Caltrans

EROSION RESEARCH FACILIT

CAL POLY

Vegetation Establishment & Maintenance Study

Volume 1

Vegetation Establishment For Erosion Control Under Simulated Rainfall

An Experiment Designed For

District 5

Central Coast

Prepared By

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Volume 1. VEGETATION ESTABLISHMENT AND MAINTAINCE STUDY (VEMS)

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2. SUMMARY

Hydroseeding failures on disturbed sites are usually attributable to combinations of improper species selection, seeding at inappropriate times, and/or improper seed mixes, fiber, and tackifier. To investigate these factors, California Polytechnic State University, San Luis Obispo, in conjunction with the California Department of Transportation (Caltrans) and California State University, Sacramento, conducted a study of these factors' affect on vegetation establishment.

The goal was to identify initially fast growing vegetation that demonstrates long-term erosion control effectiveness. Native plant species common to District 5, along the California Central Coast, were used. Treatments were conducted in 0.6 by 2 m by 30 cm soil test boxes set at a 2:1 (H:V) slope. Boxes were filled with a medium sandy loam soil (USDA), typical of District 5 fill slopes, compacted to 90 percent. Erosion control treatments included combinations of imprinted straw and hydroseeding of fiber, fertilizer, and tackifier. All boxes were planted with the same native seed mix that included shrubs, forbs, and grasses. Norton Ladder rainfall simulators were used to simulate natural rainfall patterns found in the area. The rainfall regimes applied were natural precipitation, 53.3 cm (21 in/yr during the study period) and uniform rainfall at the mean annual rate, 56 cm (22 in/yr), half the mean annual rate, 28 cm(11in/yr) and double the mean annual rate, 111 cm (44in/yr). The rainfall simulators mimicked rainfall characteristics for the California coast, such as drop size distribution, terminal velocity and a range of storm intensities. In all, 24 boxes were established and treated under rainfall simulators, eight additional boxes were subjected to natural rainfall, and two more boxes were untreated (bare soil). Percent cover and runoff quality (measured as Suspended Sediment Concentration) were measured for each box.

The boxes treated with straw and fertilizer showed greater percent cover than those treated with tackifier and no fertilizer. The ANOVA results indicated that this effect statistically significant to a high degree (p=.001). The effect on runoff was marginally significant (p=.048). Runoff volume was greatest on the heavy rainfall treatments. Higher rainfall treatments showed an increase in the quantity of the native plants of yarrow (*Achillea millefolium*), lupine (*Lupinus succulentus*), and California brome (*Bromus carinatus*). Shrubs and deer lotus (*Lotus scoparius*) were the least common species under all rainfall regimes. This project demonstrates using hydroseeding that includes tack and fertilizer is not as effective in establishing native plant cover without the treatment of straw.

The higher overall plant cover for medium rain boxes, both in box half differences and in the presence of straw and fertilizer in the lower half, suggests that experimental logistics and execution may be an unaccounted for in this experiment. As the rain season progressed, high rain boxes were receiving simulated storms about every week or 10 days. Perhaps this added water in conjunction with the colder temperatures and higher humidity

values experienced during the winter promoted cold and wet soil conditions less conducive to plant germination and growth than present among the medium rain boxes given more time to dry and warm between rain events.

These interactions among presence of straw and fertilizer, rain regime, and box half, are obviously complex with no definitive result. Higher cover values in the upper box halves for rain regimes other than natural may indicate possible differences in soil water content, soil temperature related to water content, or shading. The overall reduced response in the natural boxes is likely attributable to the very erratic and inconsistent precipitation regime peculiar to the last rain season. Overstory growth in these boxes was substantially reduced when compared with the medium boxes despite both receiving approximately the same seasonal total. Not surprisingly, understory growth was extremely poor owing to poor germination and establishment in competition with even the reduced overstory cover of Annual Ryegrass in the natural boxes.

For the understory, the percent cover with a high rainfall level, fertilizer and tackifier nets a higher percent cover than straw alone. If we adopt a 10% experiment-wide error rate, we would also conclude that fertilizer and tackifier is better than tackifier alone. The understory percent cover with medium rainfall, fertilizer and straw is preferable to straw alone. If we adopt a 10% experiment-wide error rate, we would also conclude that fertilizer and straw beat tackifier alone.

3. FINDINGS

Vegetation establishment on Caltrans sites is difficult and often not successful. Failures can be attributed to numerous items such as incorrect plant selection, timing, and rainfall patterns, application methods used in vegetation establishment and erosion control. The research completed at Cal Poly, San Luis Obispo, Soil Science Erosion Control Facility evaluated plant species with simulated rainfall patterns, similar to the central coast, and natural rainfall for the 2000-2001 season. Native plant species common to Caltrans specifications along the central coast were hydroseeded in the fall of 2000 into erosion control boxes and evaluated during the winter and spring of 2001.

Total Average Sediment

High rainfall had the most amount of sediment
High rainfall + FT had the most sediment - 10g
High rainfall + S decreased sediment to 3g
Low rainfall averaged .25% of high rainfall
Low rainfall + FS had the least sediment - 1g
Fertilized and tackifier boxes have more sediment
Straw boxes had lower amounts of sediment

Average Total SSC

Low rainfall had highest SSC
low rainfall + FS had highest SSC - 0.006g/ml
Low rainfall + S had lower SSC
High rainfall + FT had lower SSC
High rainfall + S had lowest SSC - 0.001g/ml
SSC decreases with time

Natural Rainfall

FT had most total sediment - 25g (10g for FT High)
S had least total sediment - 3g (3g for S High)
FT had highest SSC - 0.003g/ml (0.006g/ml for FS low)
FS had lowest SSC - 0.0008g/ml (0.001g/ml for S high)

Bare and Disturbed Soils

Bare High rainfall averaged 200-400g/day
High disturbed was lower than low bare
After the first day, high disturbed was almost as low as low disturbed - < 10g/day

Combined Average Sediment and SSC and Natural Rainfall Boxes

Straw decreased both Sediment and SSC overall for all treatments
High rainfall created the most amount of sediment
Straw and tackifier produced the less average total sediment for natural rainfall
Bare soil boxes undisturbed produced more sediment than roughened boxs

Vegetative Overstory

Non-nataive dominated with approximately 76% cover
Calfiornia Brome and Arroyo Lupine made up 20% of the cover
Moderate interactions
Medium rainfall increased vegetation the most
H and M rainfall + F increased vegetation
Low rainfall had no significant differences

Vegetative Understory

California Poppy and White Yharrow made up 22% of the cover
H,M, and L rainfall + S increased vegetation
H,M, and L rainfall +FS increased vegetation
Medium rainfall +FS increased vegetation in the lower box half

Combined Vegetation

Over all 32 boxes, 45 species were observed: 10 were members of the seed mix, 35 were not

Annual Ryegrass (Lolium multiflorum), an alien non-seeded species, constituted 64% absolute cover (plants + non-vegetated soil) and 70% relative cover (plants only) overall

Of the seeded species, grasses and forbs exhibited greater establishment than shrubs did

California Sagebrush (Artemisia californica) was the only seeded shrub to emerge with any success at about 1.4% cover and 216 total seedlings counted, mostly under average to high rainfall simulation

No sagebrush seedlings were observed among any of the boxes that received natural rain even though the total precipitation for the season was just above the 50-year average.

The data suggest that the natural rainfall boxes did not have a difference in cover when comparing the upper versus the lower portion of the boxes. For the upper box division, medium rainfall produces more cover than high, followed by low and finally natural rainfall boxes. The data suggest that the straw and fertilizer in the lower box halves has a higher proportion of cover in the medium rainfall when compared to the high rainfall, followed by low rainfall and finally natural rainfall.

4. GOALS

STUDY OVERVIEW

The purpose of this study was to develop guidance for effective establishment and maintenance of erosion control vegetation for rapid short-term growth and for long-term establishment. The plants examined in this study included both native and non-native or adapted species.

Caltrans can use the results of this study in an effort to decrease erosion and thereby improve water quality. There is a need to address proper seed selection, proper time of year for seeding, appropriate methods of hydroseeding, plant establishment criteria as it relates to erosion control and soil stabilization, and site maintenance needs throughout the lifecycle of the plants.

GOALS

1. Identify and select plant species for hydroseeding that demonstrate initially fast growth and long-term erosion control under a variety of rainfall regimes.

2. Characterize how various rainfall regimes affect seed germination and plant establishment.

3. Characterize how various hydroseeding techniques affect seed germination and plant establishment.

4. Measure the effectiveness of a hydroseeded erosion mix in controlling runoff under varying rainfall regimes and hydroseed application methods.

5. Design a Field Guide for establishing plants effective in rapid short and long-term erosion control.

5. LITERATURE REVIEW

The literature review is divided into four sections and issues that affect successful vegetative establishment. Below are only a few of the references identified from both referred and trade journals. The entire list of approximately 65 articles found thus far will be included on the CD. The literature review has been organized so that a matrix can be developed and incorporated into a plan of action in the establishment and maintenance of plants for erosion control. These references can then be used to develop future Caltrans projects.

A. Prioritize native versus aliens for a given site. Each site should be placed in context with the surrounding environment and land use.

   1. Title: *Differential responses to nitrogen fertilization in native shrubs and exotic.*
      Summary: Results showed that the three native shrubs tested were more nitrophilous than the three exotic annuals tested with nitrogen fertilizer. The study mentions that their findings contradict most models relating to perennial species' adaptation to stressful environments.

   2. Title: *The influence of revegetation techniques on long-term plant community development.*
      Summary. Four seeding techniques, two fertilization treatments, and three irrigation treatments were applied on severely disturbed rangelands. The study concluded that initial treatments could influence long-term plant community development on severely disturbed rangelands.

B. Examine the physical site and how it will influence plant establishment. Evaluate both the natural, inherent properties as well as human influence on the site.

   1. Title: *Soil erosion and vegetation in grasslands of the Peloncillo Mountains, New Mexico.*
      Summary. Vegetation cover and parent material alone do not explain the dynamics of sediment transport. Rather, cover, slope gradient, ground surface roughness, soil depth, and soil infiltration rates interact or regulate sediment transport during and after storm events.

   2. Title: *Seasonal Preferential Flow in Two Sierra Nevada Soils Under Forested and Meadow Cover.*
      Summary. The preferential movement of surface applied solutes is a potential source of groundwater contamination and could subsequently provide a major source of nutrients to Lake Tahoe. This study investigated seasonal infiltration, water repellency, and preferential water flow in two Sierra Nevada soil types in forest and meadow areas using a rainfall simulator.

C. The understanding how plant establishment, specification, and performance are affected by genealogy and phenotypes.

   1. Title: *Elevated CO2 Effects on Nitrogen Dynamics in Grasses.*
      Summary. Three perennial grass species were grown at two CO2 concentrations and under two nitrogen regimes. The study concluded that elevated CO2 has the potential to induce significant changes in plant nitrogen, modifying nitrogen allocation and tissue quality within perennial grasses. These effects appear to be independent of the soil microbial population.

   2. Title: *Soil Aggregate Size Effects Phosphorus Desorption.*
      Summary. The results suggest that soil management that favors soil aggregation may, in some cases, increase plant availability of applied phosphorous. Perhaps the distribution of soil aggregates should be considered in making phosphorous management decisions.

D. The benefits and problems of past and existing practices are investigated. This section addresses articles on maintenance requirements, aesthetic values, and politics.

   1. Title: *Comparative study of the capacity of germination and of adhesion of various hydrocolloids used for revegetalization by hydroseeding.*
      Summary. Hydroseeding has a beneficiary effect for seed adhesion, germination, and erosion prevention. The study concluded that there is a relationship between the viscosity of the solution and the capacity of adhesion.

   2. Title: *Effects of Mediterranean shrub cover on water erosion.*
      Summary. The natural vegetation has been shown to be the best form of soil stabilization. The native medicago reduced sediment loss by 37.^%.

   3. Title: *Effectiveness of Low-Cost Erosion Control Structures (Straw Bales) on Rills & Gullies in Southern Arizona Rangelands*
      Summary. Stated in the abstract, if erosion is left overlooked, small gullies and rills can become massive sources of sedimentation and upland degradation. This costs producers large amounts of money to rectify. A good low-cost control method is the use of straw bales when installed correctly.

6. EXPERIMENTAL DESIGN

STATISTICAL DESIGN

The experiment was designed to detect differences in both vegetation cover and runoff as a function of experimental treatment.

The vegetation cover aspect of the experiment is a 4×2^3 full factorial design with four levels for rainfall (natural, low, medium and high), two levels for fertilizer (none and fertilized), two levels for treatment (straw or tackifier) and two box divisions (upper and lower). There are two replicates at each set of factor levels. Measurements separately on each the upper and lower box division because there may be some runoff effect and because some of the lower boxes were shaded, either of which could cause the percent cover to differ. The box-division should be viewed as a blocking factor.

The runoff portion of the experiment is a 4×2^2 full factorial design with rainfall, fertilizer and treatment factors is in Table 6.1.

Table 6.1 Factor Levels

Factor	Levels	Design Amount	Actual amount (mean, minimum, median, maximum)
Rainfall	Low	28 cm	28, 28, 28, 28 cm
	Medium	56 cm	57, 51, 58, 58 cm
	High	84 cm	84, 79, 84, 89 cm
	Natural	Natural precip	55 cm
Fertilizer	No Fertilizer	0	
	Fertilizer	40 units/acre	
Treatment	Straw	2240 kg/ha	
	Tackifier	168 kg/ha	

Both aspects of this experiment have a possible confounding factor, microclimate. It was necessary to put the soil boxes into fixed position for the duration of the raining season and for safety and convenience the boxes were located so that those requiring more simulated rainfall were easier to access. Thus, the experimental units were not randomly located and could possibly be influenced by local microclimates caused by shading and wind. We cannot completely control for these factors at the analysis stage because they are confounded with treatment. However preliminary attempts to control for these microclimate blocks suggests that boxes in similar locations have similar percent cover values above and beyond what would be predicted by rainfall regime and treatment alone.

BOX SIZE DETERMINATION

Two criteria were used to determine the size of our erosion test boxes. The first criterion was that the plot (box) size had to be a precedent in the erosion literature. The other criterion was that the boxes had to be of a size and weight that could be easily handled by two people using a simple one-ton chain hoist that was preexisting at our test site. Pearce et al. (1998) utilized field micro-plots of 0.6 meter by 2.0 meters alongside standard plots of 3.0 m by 10 m. A box having the same dimensions as the micro-plots, combined with a soil depth of 8 inches, weighed less than a ton when saturated and were easily moved by two people using the preexisting hoist.

HYDROSEEDING DESIGN

Hydroseeding was performed to specifications standard for the District 5 Central Coast region. The specifications were obtained from past projects that were installed within the last five years in District 5. KarlesKint-Crum, Inc., Licensed Landscape Erosion Control Contractors, performed the application.

Treatments included eight boxes sprayed for each individual treatment listed below. The rate of fiber was applied at 896 kg/ha (800 lbs/acre). The fertilizer was applied at 45 kg/ha (40 lbs/acre) of 15-15-15. The straw was crimped into the soil at 2240 kg/ha (2000 lbs/acre). The tackifier was applied at 168 kg/ha (150 lbs/acre). A native seed mix was applied to each box. The treatments were:

1. fiber, seeds, and crimped straw
2. fiber, seeds, and tackifier
3. fiber, seeds, fertilizer, and crimped straw
4. fiber, seeds, fertilizer, and tackifier

Boxes were placed in a random design before hydroseeding. Prior to hydroseeding, rice straw was crimped into sixteen boxes for treatment 1 and 3. The first pass was loaded with fiber and seed for treatments 1 and 2 and sprayed sixteen boxes in total. Fertilizer was then added for a second pass and the mixture was sprayed on treatments 3 and 4, sixteen boxes in total. The equipment was then cleaned out with water and set up for the third pass which was fiber for treatments 1 and 3, 16 boxes in total. Tackifier was loaded for the fourth pass on treatments 2 and 4, 16 boxes in total.

RAINDROP SIZE

The average drop size for the rainfall simulators was 1.72 mm and they ranged in size from 0.5 to 5.0 mm. The average drop size for most storms is 2 to 3 mm.

RAINFALL PATTERN

Two design storms were written for the simulations of the erosion test boxes. One storm consisted of one inch of rain in two hours. The second consisted of two inches of rain in three hours. Intensities in these storms are slightly higher than the accepted average of an inch in four hours. Rain from these design storms was delivered in a bell shaped design. Storm rates increased linearly as shown below in Figure 6.1.

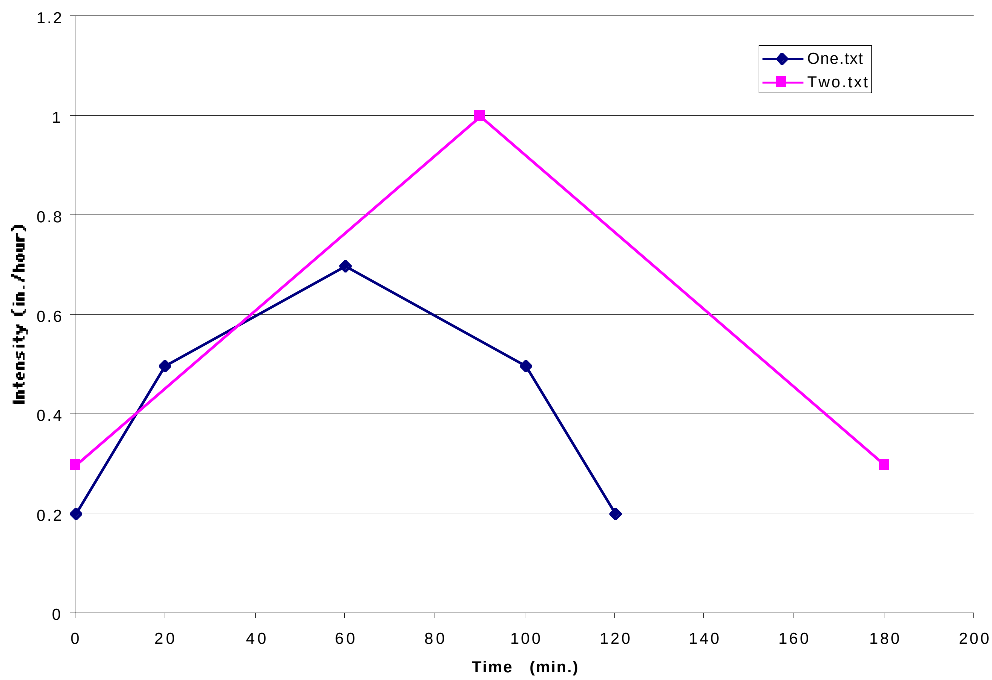


Fig 6.1 Intensity Flux of Design Storms With Time

7. METHODS AND MATERIALS

SET-UP AND CONSTRUCTION

7.1.1 RAINFALL SIMULATORS

Two Norton ladder type variable sweep rainfall simulators were purchased for use in this study. This type of simulator was developed by Darrell Norton, Ph.D., of the USDA Erosion Research Center at Purdue University. Advanced Design and Machine (Clarks Hill, IN) manufactured the simulators. The purchase price of the Norton rainfall simulators included an aluminum framework to erect them in the field. An alternate system was designed for supporting the simulators at the Erosion Research Facility, which was of adequate height to allow raindrops to reach terminal velocity.

The Norton rainfall simulator is a pressurized nozzle type simulator, the most frequently used simulator in erosion research. It consists of a boom oscillating side to side by way of a cam. A small motor drives the cam at one end of each simulator. Intensity of rainfall is determined by how many times the nozzles of the boom sweep s past the box opening. The boxes are configured to regulate spray pattern and return non-effective rainfall to the water supply system. Water delivered from these simulators was deionized through cation and anion exchange columns.

Norton rainfall simulators use Veejet brand nozzles manufactured by Spraying Systems Company . These are the most common types of nozzle used on previous rainfall simulation studies. At 41 kilopascals (kPa) (6 lbs/in$^{2)}$, the nozzles should create a drop size of about 2.25 millimeters (mm) in diameter. This drop size corresponds to the average drop size of erosive storms in the Midwest. The Veejet nozzles are industrial spray nozzles that are used in high-pressure spray applications. They have an optimum range of 5 to 300 psi and are run at 6 psi. for rainfall simulation purposes.

A control box supplies power to the simulators and signals them when to sweep. The control box has been quite problematic throughout this study. The electronic hardware found inside the box was barely adequate to power two 120 VAC motors. Components in the control box are running at capacity at all times and system shutdowns were frequent. This problem was minimized by the addition of a cooling fan added to the box.

7.1.2 BOX CONSTRUCTION AND SUPPORT STRUCTURES

In January of 2000, a prototype erosion test box was built with the aid of a design from Clint Iwanicha Designs (Morro Bay, CA). The erosion test box was built at the Erosion Research Facility in March of 2000. The design called for the use of pressure treated lumber for outdoor applications. The lumber is treated with chromated copper arsenate and is considered safe to humans in all reasonable applications. Boxes constructed for the project differ slightly from the prototype. An extra 61X122 cm (2X4 ft) was placed at the base of the box to support the soil load and to allow the steel mesh at the base of the box to remain more rigid under load.

A total of 36 erosion test boxes, each measuring 2 m (78 in.) long by 61 cm (24 in.) wide by 30.5 cm (12 in.) high, were constructed and filled with soil. One end of each box was cut to a height of eight inches to coincide with the height of the added soil. Four of the boxes were not used in the study. Boxes were assembled using a drill press, mitre box saw, and a variable speed hand drill.

In addition to the erosion test boxes, Clint Iwanicha Designs created plans for a support stand. Ten of these supports were used in this study. The supports, also constructed with pressure treated lumber, use a one-inch diameter, schedule 40, galvanized steel pipe to support the boxes at a 2:1 slope. Supports were used for the two boxes during a simulation and the eight natural rainfall boxes.

Each box had a designated space under the box transport system. The erosion test boxes were situated next to each other, 5 boxes per row with a total of 5 rows. One space was remained empty for the duration of the experiment because there was only 24 boxes to be exposed to simulated rainfall.

7.1.3 RAINFALL COLLECTION SYSTEMS

7.1.3.1 Simulated rainfall collection system

A length of vinyl gutter was used to collect runoff from the base of the erosion test box and channel runoff into a basin for collection. A rectangular piece of synthetic pond liner was cut and riveted over the vinyl gutter. This prevented simulated rainfall from entering the runoff collection system. The collection system was secured to the box with screws. The collection basin consisted of an eight quart Rubbermaid container, trimmed to accept the curve of the gutter. These collection systems were closed, but could be removed and attached to the boxes that were currently under the rain simulators.

7.1.3.2 Natural rainfall collection system

Eight Rubbermaid bins, 75.6 L (20 gal) each, were placed in hand-dug sumps just off the concrete slab adjacent to each of the natural boxes. The sumps were dug to a depth of twice the height of a collection basin. A perforated polyvinyl chloride tube was inserted into each sump and float rock was added around the tube to half the depth of the hole. This allowed the removal of water from the sumps using a bilge pump after a storm.

A length of 10 cm polyvinyl chloride drain pipe connected the collection system at the base of each erosion test box to a 75.6 L collection bin. A 90-degree fitting connected the drainpipe to an opening in lid of the bin. Runoff collection was isolated from contamination by a few simple precautions. To prevent rain not falling directly on the box from entering the gutters, a rubber sheet was stapled over the end of each gutter. To prevent leaf litter from entering the gutters, silt fence material was hung just above the entrance to the gutter where runoff flows into the gutter.

7.1.4 SITE SET-UP AND CONSTRUCTION

- Started with a level site with buildings., asphalt parking & soil @ approx. 1393.5 m^2 (15,000 sq.ft or 100'x150')
- Utilized some large existing asphalt areas
- Utilized existing steel barn (head house) for purposes such as construction and testing
- Site had good to fair sun exposure
- Rough site was graded at 2% slope with Bobcat skid steer for proper drainage
- Concrete slabs were poured to approx. 102 m^2 (100 ft^2 (49'x18' and 65'x17')
- Utilized existing steel girder structure 19 m by 3.3 m by 4.5 m (64' long, 11' high, & 15' wide)
- Built box storage racks on new concrete slabs versatile enough to change slope of box
- Surface drained necessary areas with swales to alleviate pooling of water
- Dug sumps for natural box runoff recovery
- Applied gravel in appropriate areas to alleviate muddy spots not covered by concrete or asphalt
- Planted lawn to reduce glare and drying effects of concrete slabs

7.1.5 WEATHER STATION

A weather station was set up in order to monitor the daily weather conditions at the simulation site. The weather station was mounted directly above the simulated rainfall boxes to effectively interpret the conditions surrounding the boxes. The weather monitoring station was linked (wirelessly) to a computer kept in the head house that logged weather data throughout the experiment.

Set-up for Simulated Box Monitoring:

- Davis Wireless Weather Monitor II Weather Station: This data collector was selected for its relatively low cost and rugged construction. The unit was self-contained, using a solar panel as an energy source. The sensors were contained in a rugged plastic housing. This unit sent data (via a radio frequency) to a receiver in the head house to collect data.
- Weather Link Data Logging Software (PC version) and Data Logger: This software was run on a custom built 486 computer, which downloaded data from the logger every five minutes. The computer and data logger were attached to an APC UPS 650va battery backup to allow two hours of uninterrupted data logging in the event of a power loss.
- Data Collection: Rain is measured via a tipping bucket rain gauge. This tipping bucket measured rainwater in 0.0254 cm (0.01in) intervals. Temperature, relative humidity, wind speed, wind direction, and dew point were all measured and recorded every five minutes along with the quantity of rain delivered.

SIMULATED RAINFALL OPERATIONS AND PROCEDURES

To perform a rainfall simulation, a series of directions were followed to ensure each simulation was a repeatable event. The directions were followed to ensure the safety of those involved with this study.

Prior to a simulation, two erosion test boxes were moved into place beneath the simulators. It was necessary at this time to check the schedule of simulations in the laboratory notebook to ensure the appropriate boxes were in place.

Although the design of the box transport system allowed each box to be moved by one person, it was preferred to have two people assisting in the placement of the boxes. This expedited the process of moving the boxes and, more importantly, increased safety. Any person assisting in the movement of the boxes was required to wear a properly fitting hard hat. Gloves were also required if the person was operating the chain hoist.

7.1.6 Box positioning procedure

To lift the erosion test box, the I-beam containing the hoist directly was positioned over the box. Three heavy-duty nylon straps, each with a capacity in excess of the weight of a saturated erosion test box, were used to cradle box. The hoist, rated at one ton, lifted the box at the union of the straps. After each rainfall simulation, the two boxes are moved back to their respective locations within the box transport system using the same procedures used to move them into place. To position boxes for simulation, two box supports were utilized. The bar was set at the 2:1 (H:V) slope position for every simulation performed this year. Markings painted on the concrete beneath the simulators aided in the expedient and proper placement of the box and support stands.

After the boxes were set in place, the erosion collection systems were installed. These collection systems were appropriately masked with synthetic rubber pond liner trimmed to a size capable of preventing simulated rainfall over spray from entering the collection system. The erosion collection systems were secured with 4 Phillips screws.

Prior to a rainfall simulation event, the hoses supplying the deionized water to the simulators were attached from the manifold to each simulator. To start the flow of deionized water, the valve at the base of the water storage tank was opened prior to turning on the Jacuzzi pump. This ensured a long life for the pump.

Using a ladder, fine-tune adjustments were made using the C-clamps on the supply hoses to ensure 6 psi at the nozzles.

7.1.7 Computer

A 486 Compaq Armada laptop was used to run the rainfall simulations. A program called varisim.exe, which was developed by the USDA Soil Erosion Laboratory for use with their rain simulators, was run. Two storms were designed to deliver rain (deionized water reaching terminal velocity) to the boxes. The first was a two-hour storm, delivering one inch of rain. The second storm delivered two inches of rain in three hours. Future rain simulators will be controlled via a proprietary LabView program written by Cal Poly. The program will be written to employ National Instruments PCMCIA I/O cards in PC or Macintosh laptops.

The computer power supply and the simulator control/relay box were plugged into the extension cord inside the green house. The connector between the control box and the computer was secure and then the Amphenol connectors were fastened between the simulator motor/solenoid box and the control box.

When the prompt on the computer screen asks for a continuous or variable intensity rainfall pattern, select #2 for variable intensity. Type in the desired file name for the rainfall amount chosen for a particular simulation. Type “one.txt” for a one inch, two-hour storm or type “two.txt” for a two inch, three-hour storm. On the control box, flip the switches for gear motor and signal box controller to the on position. Make certain the switch for computer or self-timer control is activated for computer control. Press the “F10” key to begin tracking the simulation with the computer. The nozzle sweep activation switch can now be switched to the on position and the simulation will begin

HYDROSEEDING

Treatments (8 boxes sprayed for each individual treatment listed):

1 fiber:compost, seed, and crimped straw

2 fiber:compost, seed, and tackifier

3 fiber:compost, seed, fertilizer, and crimped straw

4 fiber:compost, seed, fertilizer, and tackifier,

The hydroseeding was conducted by Karls-Kint and Crumb Landscape Materials Center. Prior to hydroseeding, rice straw was crimped into sixteen boxes. The spray tank was run in a specific order so as to not mix the treatments and save time and money. Boxes were randomly placed in rows in accordance with the run before the hydroseeding event. Run one was loaded with seed, fiber, and compost, where treatments 1 and 2 were sprayed (16 boxes). Fertilizer (15-15-15) was added and the entire mixture was sprayed on treatments 3 and 4 (16 boxes). Run two was only fiber and compost and treatments 1 and 2 were sprayed (16 boxes). Tackifier was loaded and treatments 2 and 3 were sprayed (16 boxes).

The operator hydraulically sprayed the boxes in a uniform fashion by holding the nozzle with arms fully extended above the head and sweeping each box individually. The treatments are identified in Table 7.1.

Table 7.1 Treatments

Pass	Layer Depth	Pounds/ Acre	Treatment 1	Treatment 2	Treatment 3	Treatment 4
		300:120	fiber : compost	fiber: compost	fiber : compost	fiber compost
1	~3 cm	40	no fertilizer	no fertilizer	fertilizer	fertilizer
		40	seed	seed	seed	seed
			crimped straw	no straw	crimped straw	no straw
2	~5 cm	150	no tackifier	tackifier	no tackifier	tackifier
		500:200	fiber : compost	fiber : compost	fiber : compost	fiber : compost

RUN-OFF COLLECTION

7.1.8 Simulated Rainfall Sediment And Runoff Collection

While a simulation was in progress, it was necessary to monitor both the activity of the simulators and the volume of runoff contained in the collection basins. Basins frequently became full prior to the completion of the simulation. The contents were carefully transferred to another container to prevent loss of runoff due to over flow. Two pails, separately labeled, were used to transfer the runoff from the respective collection basins.

Various containers were used throughout this study to store runoff after a simulation, but prior to analysis. Regardless of the liquid previously stored in the containers, each was washed with dish soap and rinsed well with deionized water.

Each container used for sample storage was labeled using permanent ink pen with the following information: date of simulation, erosion test box #, simulator #, and total volume of deionized water used to rinse the samples. In addition, if more than one container was needed to collect sediment/runoff for a specific box and rainfall event, the series (e.g. 1/3, 2/3, etc.) was identified on all of the associated containers.

To begin runoff collection, the collection system from each box was removed one at a time. An amount of 500 mL of deionized water was added to a laboratory wash bottle. Sediment adhering to the collection gutter was flushed into the collection basin. Runoff contained in collection basins was carefully poured into properly labeled runoff collection containers. A funnel was used to prevent loss of runoff through spills.

The wash bottle with remaining deionized water (there should be ~300 ml) was used to assist in flushing sediment remaining in the runoff collection basin into runoff containers.

Before reinstalling collection systems on the next set of boxes, the collection systems were completely rinsed to remove sediment from the black rubber over spray guard.

7.1.9 Natural rainfall collection

After a significant natural rainfall event, any runoff in the 75.6 L (20 gal) bins was collected. Using a 11.4 L (3 gal) Hudson Bak-Pak sprayer, two liters of deionized water was used to flush the collection system of each natural rainfall test box. Any sediment adhering to the walls of the collection system was flushed into the collection bin via the sprayer. The runoff was then transferred to a five-gallon bucket, using the water remaining in the sprayer to ensure all sediment was rinsed into the bucket.

Each bucket was covered and labeled with the date of collection, type of precipitation (natural), box number, and the addition of two liters deionized water.

WATER QUALITY ANALYSIS

The two most common methods of measuring suspended sediment in water are Suspended Sediment Concentration (SSC) analysis (ASTM D3977-97) and Total Suspended Solids (TSS) analysis (EPA Method 160.2). One major difference between these two methods is that SSC utilizes an entire sample for sediment analysis, whereas

TSS utilizes a small portion (aliquot) of the original sample. Because TSS uses a smaller sample, it often becomes the preferred method due to time and money savings over SSC. Although TSS has been widely utilized as a replacement for SSC, there are fundamental problems associated with it. These problems lead to the production of data that are negatively biased from 25 to 34 percent when compared to SSC data from samples taken at the same time and same location as TSS samples (Gray and Glysson, 2000).

The major problem with TSS is the inability to reliably extract an aliquot of suspended sediment from a water sample. Particles in suspension vary in size and settling time; therefore, it is inherently difficult to shake or suspend all sample particles evenly throughout the sample and then to pull an aliquot before any significant settling has occurred. This is especially true for sand-size particles in a sample (due to their high settling rate). Use of different methods of aliquot extraction and the individual techniques of laboratory personnel compound the difficulties associated with accurate TSS analysis.

In order to avoid the problems associated with TSS and in order to obtain the most accurate measure of sediment concentration possible, a modified version of ASTM D3977-97 was used as our method for water quality analysis. We felt it was of utmost importance to utilize the most accurate method possible because of our relatively small box size (0.6 m by 2.0 m) compared to the standard plot size of 3.0 m by 10 m for most simulated rainfall studies. Additionally, the rather small sizes of entire samples (~0.5 L to 3.5 L) lent themselves to analysis in their entirety.

Test Method A (Modified Evaporation) or Test Method B (Evaporation) described below:

Test Method A: Modified Evaporation

This method was utilized when most of the solid material in the liquid had settled down from suspension. Two measurements were obtained: final filter weight and final evaporation weight. The summation of these two measurements yielded the total sediment weight. This sediment weight was divided by total water volume (determined by the weight of water) to yield Suspended Sediment Concentration (SSC) for given sample.

Supernatant water (clear, overlying water, which contains mainly fine sediment) was slowly filtered through a vacuum-filtration manifold. The supernatant water was decanted onto oven dried, pre-weighed Whatman 934AH filter paper. Filters were then oven dried for a minimum of eight hours at a temperature of 115 degrees Celsius. After oven drying, filters were placed into a desiccator. A desiccator prevented air-borne moisture from collecting in the sediment specimens while the filters were cooling. After filters were at room temperature, an analytical balance was used to obtain the final filter weight.

Once the supernatant water was filtered, the remaining water-sediment mixture was flushed from the storage container into a pre-weighed Nalgene evaporation beaker. The additional water amount used to flush the water-sediment mixture did not affect final calculations for any data analysis. Multiple evaporation beakers were required for most samples. Evaporation beakers were then oven dried at a temperature of 115 degrees Celsius until all water was evaporated. Since most of the evaporation beakers were over 2 liters in volume and too large for the desiccator, a desiccator was not used for the evaporation beakers. After the evaporation beakers were at room temperature, a digital balance was used to obtain the final evaporation weight of sediment.

The final filter weight combined with the final evaporation weight yielded the total sediment weight for given sample. This sediment weight divided by total water volume yielded SSC for given sample.

Test Method B: Evaporation

This method was utilized when most of the solid material in the liquid had not settled from suspension. One measurement was obtained: final evaporation weight. The final evaporation weight yielded the total sediment weight. Total sediment weight was divided by total water volume (determined from the weight of water) to yield SSC for given sample.

An entire sample was poured into a pre-weighed Nalgene evaporation beaker. Multiple evaporation beakers were needed for most samples. Evaporation beakers were then oven dried at a temperature of 115 degrees Celsius until all water was evaporated. Since most of the evaporation beakers were over 2 liters in volume and too large for the desiccator, a desiccator was not used for the evaporation beakers. After evaporation beakers were at room temperature, a digital balance was used to obtain the final evaporation weight.

The final evaporation weight yielded the total sediment weight. This total sediment weight divided by total water volume yielded SSC for given sample.

Although turbidity is a common and useful characteristic of runoff and can be easily measured, it was not measured in this study. The reason for exclusion of turbidity analysis was due the method of runoff collection. In order to collect entire runoff samples, the collection systems were flushed with a quantity of water (as described in the Rainfall Collection section of this report); and in doing so, the turbidity value of each sample was diluted. In future studies, turbidity will be measured at the completion of each simulation and before any flushing of the collection system occurs.

Sediment concentration data are presented in section 8.1.4.2 concentrations are repeated in total sediment concentration.

Results for our analysis of sediment concentration are presented in the Water Quality section of the Results and Discussion.

VEGETATION ESTABLISHMENT AND ESTIMATES

The three primary measures of vegetation are: ***density***, the number of individuals of a species, lifeform, or structural class per unit area; ***biomass***, the quantity of herbaceous or woody tissue produced by individuals of a species, lifeform, or structural class per unit area; and ***cover***, a two-dimensional perpendicular projection down onto the ground surface of the three-dimensional aerial vegetation above (Bonham ,1989; Interagency Technical Team, 1996; Kent and Coker, 1992; Mueller-Dombois and Ellenberg, 1974).

For this first rainfall simulation experiment, plant cover was chosen to assess the affects on soil erosion of vegetation establishment under different hydroseeding treatments and rainfall regimes. Cover is the most logical and time-efficient measure in that the interception of raindrops by aerial plant parts is fundamental in retarding water-driven soil erosion processes. Although plant density can provide important information about how many individuals of a given species in a seed mix germinated and established, obtaining plant counts are extremely labor intensive and time consuming, especially in a multi-species mix. Therefore, a separate upcoming experiment was devised to measure the density, using individual, single-specie test boxes and known quantities of applied seed. Biomass is a measure of site-dependent plant productivity. The measure of biomass requires destructive sampling, intensive labor, and extensive time, and was not performed; as such, measurements would likely not repay their costs nor provide additional information beyond cover estimates.

Although ***cover*** is the most frequently employed vegetation measure, the term "cover" includes a multitude of possible measurement techniques, and connotes different meanings to different people (Bonham, 1989). Therefore, an explicit discussion of the exact method(s) used to measure plant cover for any research project is imperative.

Valid estimates of plant cover are difficult owing to some complex and interacting factors:

Plants are spatially three-dimensional, stratified, and interwoven;

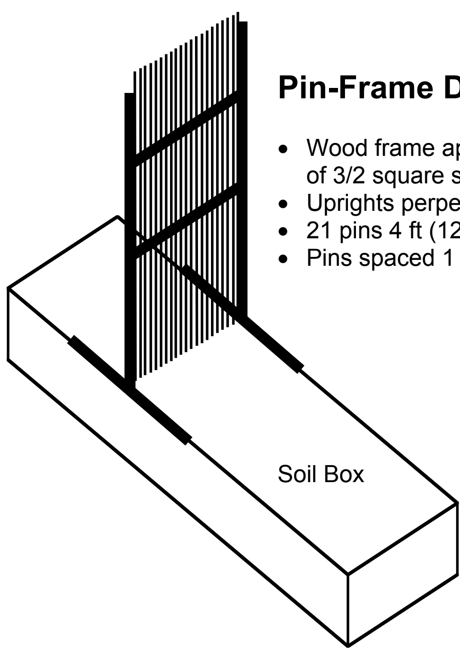
Plants are variable over space and time;

Plant sizes and shapes influence the spatial dispersion of "hits" (i.e. the spacing of observation points must not be too closely or widely spaced for the vegetation).

The oldest, most objective, and most repeatable measure of plant cover is by *point intercept* whereby a theoretically infinitely small point projected from above down onto vegetation surfaces contacts individual plant structures, soil surface litter, rock, or bare soil. Each contact is termed a "hit" for each category scored. Rules must be established beforehand regarding exactly what constitutes a "hit" for each purpose-dependent investigation. For example, for studies of long-term plant cover "hits" upon inflorescences may not be counted owing to their ephemeral presence. However, other studies, such as this one, may choose to count "hits" upon inflorescences because such plant organs do intercept raindrops when present during the season of precipitation.

Although the best point method for cover measurements is through an optical sighting device (a tube with lenses and cross-hairs analogous to a short-range telescope) mounted on a frame and directed along an axis perpendicular to the ground surface, the observer must sight through the device from directly above or to the side. Because our test boxes are inclined at a 2:1 H:V (=50% = 26.6°∠) slope, and not readily movable to a position flat on the ground, an optical sighting device was not used. Instead, a pin-frame, the next-best traditional method for measuring cover over small areas, was used for cover analyses.

We designed and constructed a custom pin-frame using wood and stainless steel rods as pins. The frame is designed such that the uprights are perpendicular to the actual ground surface, not to the soil in the box, because the vegetation in the boxes is growing perpendicular to the actual ground surface due to plant phototropism. The frame contains 21 independently operated pins in a single row, each approximately 122 cm (4 ft) long and spaced 25.4 mm (1 in) apart. This length accommodates increasing plant height as plants grow through the season. Pin spacing reflects the finely textured, mostly grassy, nature of the vegetation growing in the soil test boxes, and the need to include as many potential sample points as possible in our randomized sampling scheme.



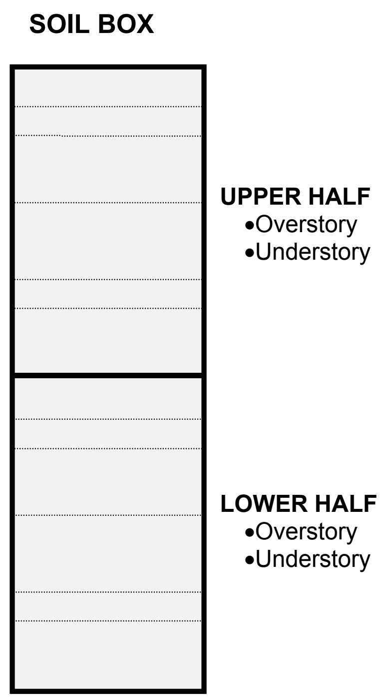
Pin-Frame Details

- Wood frame approximately 4 ft (122 cm) tall by 2 ft (61 cm) wide of 3/2 square stock
- Uprights perpendicular to the actual ground surface, not to the soil in the box
- 21 pins 4 ft (122cm) long of 5/32in (4 mm) diameter stainless-steel
- Pins spaced 1 in (25.4 mm) apart in a single row

The 21-pin design of the pin frame allows for two different sampling schemes. A standard method where 20 pin positions are sampled consecutively with the remaining pin position used to randomly select a starting position at pin 0 or 1. A second method randomly selects a subset of pins from the 21 positions possible. The latter method was chosen for our initial cover estimates, because it reduced the affect of spatial autocorrelation in the data set. Spatial autocorrelation is an important and complex issue in statistical analyses of spatial phenomena and too large of a topic for in-depth discussion here. In brief, the issue simplifies to this: spatial autocorrelation among observed values occurs where the value of a measured variable at one spatial location positively or negatively influences the value of that same variable at adjacent or nearby locations (Cliff and Ord, 1973; Fortin et al., 1989; Legendre, 1993).

7.1.10 Sampling Method

An outline of the sampling method devised to obtain plant cover estimates for the soil test boxes is presented below. Our design rendered 100 observations per vegetation layer (overstory or understory) per treatment. Thus, 3200 observations of overstory, and 3200 observations of understory, for a total data set of 6400 observations upon 32 boxes. For consistency, the same experienced observer (Curto) made scoring decisions for all 6400 observations over approximately 32 hours of scoring time. Plant identifications were made based largely on observer knowledge of the flora. Verifications of some preliminary identifications were made using the most recent taxonomical manual (Hickman 1993), and specimens in the Hoover Herbarium at Cal Poly. Data were then entered into a computer spreadsheet and verified for accuracy and completeness. The sampling methodology was as follows:



2 boxes (replicates) per treatment

2 divisions per box

For sampling purposes, each soil test box was conceptually divided into an upper and a lower half to assess whether differences in plant cover exist between the two halves because of greater gravity water flow and retention in the lower end of each inclined box.

5 transects per box division (randomly spaced)

Positions were marked every decimeter along the rails of each box. This rendered nine possible transect positions in each half of every box. We then used a computer spreadsheet to assign randomly generated numbers to each of the nine possible positions, to sort the nine positions, and to select the first five unique positions for each box. Positions selected for the upper half were used for the lower half of the same box.

10 sample points per transect (randomly selected)

A computer spreadsheet was again used to assign randomly generated numbers to each of the 21 possible pin positions, to sort the 21 positions, and to select the first 10 unique positions for each transect. Positions selected for the five transects in the upper half were used for lower half transects of the same box.

2 vegetation layers (overstory / understory) per transect

Vegetation among the soil boxes is visibly stratified into two layers: an *overstory* consisting of mostly taller grasses, and an *understory* of shorter annuals, first-year shoots of perennial forbs, and shrub seedlings. To separate the treatment responses of these shorter plants from the faster growing and taller grasses, "hits" were recorded in the overstory and understory separately. As each pin was pushed down into the vegetation, a single contact "hit" was recorded for any part of any species in the overstory. The same pin was then pushed further down until a single contact "hit" was made with any part of a different set of species occupying the lowest vegetation layer.

7.1.11 Proportion Cover

Proportion cover will be analyzed via each of three methods, logistic regression, a weighted analysis of variance (ANOVA) and ANOVA on arcsine root transformed data. Although our conceptual model of how rainfall, treatment and other factors affect each of these response variables is the same with each method, each makes a different set of assumptions before the results should be trusted. If all three methods produce largely similar results, both in terms of estimated effects of each treatment factor and in terms of the estimated proportion cover, it should be viewed as confirmation of our conceptual model. While proportion cover estimates are informative and perhaps the easiest method for comparison between treatments (light-versus heavy rainfall, etc.) they do not allow for formal conclusions so we will be using formal statistical tests appropriate to each method will be used for any hypothesis testing.

What follows is an attempt to provide a brief description of each of these methods, but the fine points of using each method for estimation or testing should are best described in any of the standard reference books. Suggestions include Agresti's *An Introduction to Categorical Data Analysis* for a discussion of logistic regression and Montgomery's *Design And Analysis of Experiments* as a reference for ANOVA.

The conceptual model relating various experimental factors to the observed proportion cover in the context of each method is described by logistic regression and ANOVA. First, logistic regression. Percent cover is measured in each box-half by determining cover or no cover for each of 50 points. If we consider the presence or absence of plant matter at each sampled location as the response variable of interest, we relate that to the experimental factors. Logistic regression is a method by which we can model the presence of plant matter at any point in the box as a function of rainfall level, treatment and other factors. If we consider any location with a fixed rainfall regime, fertilizer level, treatment (straw versus tackifier) and box-half (upper versus lower) we model the probability that at there is plant material at this location. I.e. the probability of cover at a location in the l^{th} box division with the i^{th} rainfall level, j^{th} level of fertilizer, k^{th} level of treatment (straw or tackifier) is π_{ijkl} which is modeled as:

$$\begin{aligned}\operatorname{logit}(\pi_{kjkl}) = \log(\pi_{kjkl}/(1-\pi_{kjkl})) \quad &= \quad \mu + \alpha_i + \beta_j + \gamma_k + \delta_l + \\ &\qquad \alpha\beta_{ij} + \alpha\gamma_{ik} + \alpha\delta_{il} + \beta\gamma_{jk} + \beta\delta_{jl} + \gamma\delta_{kl}\end{aligned}$$

where

α_i	Effect of rainfall level *i*
β_j	Effect of fertilizer level *j*
γ_k	Effect of treatment level *k*
δ_l	Effect of Box-division *l*

$\alpha\beta_{ij}$	Interaction between rainfall level *i* and fertilizer level *j*
$\alpha\gamma_{ik}$	Interaction between rainfall level *i* and treatment level *k*
$\alpha\delta_{il}$	Interaction between rainfall level *i* and box-division level *l*
$\beta\gamma_{jk}$	Interaction between fertilizer level *j* and treatment level *k*
$\beta\delta_{jl}$	Interaction between fertilizer level *j* and box-division *l*
$\gamma\delta_{kl}$	Interaction between treatment level *k* and box-division *l*

[Note: an interaction between, say, rainfall level and box-division would imply that the effect of rainfall level on proportion cover differs between the two box-divisions.]

Thus, logistic regression attempts to model the proportion of "successes" (in our case the percent cover) as a function of these other factors.

Next is the same model described in the ANOVA context. We propose two ANOVA methods for analyzing these proportion cover data. The first method is to model the proportion cover directly with a weighted ANOVA and the second approach is to use a transformation of the proportion cover data which will then be modeled with a straightforward ANOVA.

For the weighted ANOVA, the following model was used to describe the relationship between experimental factors and proportion cover:

$$\begin{aligned} y_{kjklm} = {} & \mu + \alpha_i + \beta_j + \gamma_k + \delta_l + \\ & \alpha\beta_{ij} + \alpha\gamma_{ik} + \alpha\delta_{il} + \beta\gamma_{jk} + \beta\delta_{jl} + \gamma\delta_{kl} + \\ & \varepsilon_{ijklm} \end{aligned}$$

where y_{ijklm} is the proportion cover for the l^{th} box division of the m^{th} box with the i^{th} rainfall level, j^{th} level of fertilizer, k^{th} level of treatment (straw or tackifier) and the main effects and interactions are exactly analogous to the terms defined in the discussion of our model in the previous paragraph. According to these models, percent cover is effected by the rainfall level, fertilizer, treatment (straw versus tackifier) and box division. The two-way interaction terms allow for the effect of fertilizer on percent cover to depend on the rainfall level (etc). We assume the ε_{ijklm} terms to be normally distributed and independent of each other. Due to the fact that our response variable is proportion data, we need to assume that the variance of the ε_{ijklm} terms is equals $p_{ijkl}(1 - p_{ijkl})$ where $p_{kjkl} = \mu + \alpha_i + \beta_j + \gamma_k + \delta_l + \alpha\beta_{ij} + \alpha\gamma_{ik} + \alpha\delta_{il} + \beta\gamma_{jk} + \beta\delta_{jl} + \gamma\delta_{kl}$ is the theoretical proportion cover. We will perform a weighted ANOVA where the analysis weights depend on estimated sample variances based on the nature of how our data were collected. Thus, if the sample proportion of cover in any box-half is estimated to be $\hat{p}$ the analysis weights for that box-half would be proportional to $\frac{1}{\hat{p}(1-\hat{p})}$.

However, because in some cases 100% of the sampled points were with vegetation cover we adopt Agresti's suggestion of adding two successes and two failures to our data for the purpose of estimating sample weights (see Agresti, 1998). Thus the sample weights for a box-half are proportional to $\frac{1}{\tilde{p}(1-\tilde{p})}$ where $\tilde{p}$ equals the number of sample points with vegetation plus two over the number of sampled points plus four. [Note: other ways to consider for sensitivity analysis would be bayes or shrinkage estimated weights or weights that are based on the fitted estimated values (starting with no weighs) in the previous iteration and iterate until stable.]

Another approach could be to transform the response variable so that we have approximate normality of the disturbance terms. One common transformation is the arcsine root transform. Thus our model remains:

$$
\begin{aligned}
y_{kjklm} \quad = \quad & \mu + \alpha_i + \beta_j + \gamma_k + \delta_l + \\
& \alpha\beta_{ij} + \alpha\gamma_{ik} + \alpha\delta_{il} + \beta\gamma_{jk} + \beta\delta_{jl} + \gamma\delta_{kl} + \\
& \varepsilon_{ijklm}
\end{aligned}
$$

but y_{ijklm} is the arcsine of the square root of proportion cover for the l^{th} box division of the m^{th} box with the i^{th} rainfall level, j^{th} level of fertilizer, k^{th} level of treatment (straw or tackifier) and the main effects and interactions are exactly analogous to the terms defined in the discussion of our model in the previous paragraph. We assume that the ε_{ijklm} terms are independent of each other, normally distributed and with constant variance.

A benefit of the weighted ANOVA over the arcsine root transformed response data ANOVA is that the interpretation of the parameter estimates is natural (i.e. parameter estimates may be thought of as the estimated difference in proportion cover between, say, high rainfall level and natural rainfall, all other things being held equal). A drawback of the weighted ANOVA is that there is no guarantee that the estimated proportion cover will fall in the zero to one range. Two benefits of the arcsine root transformation is that the estimated proportion cover will always be in the zero to one range and that post-hoc comparisons of treatments are straightforward. A drawback of the arcsine root transformation is that the parameter estimates do not have a natural interpretation.

Between the three methods, we would suggest that logistic regression should be thought of as most appropriate for estimating the effects of each factor on the proportion cover. However, we use the arcsine root ANOVA for making comparisons across the various treatments within each rainfall regime. For the post-hoc comparisons we will be using Bonferroni based methods because they are conservative and thus we are rather unlikely to conclude there is a difference between two treatments if, in fact, there is no difference.

7.1.12 Runoff Analyses

Suspended sediment concentration (SSC) were obtained for 300 separate rainfall events in our simulated rainfall boxes. When the methodology for obtaining SSC yielded a negative SSC (either by estimated negative sediment weight or by estimated negative water weight) we dropped the data point from our analysis. Also note that in two instances the estimated sediment weight was below the measurable level and assumed to be 0.000 grams. SSC (in mg/l) were estimated as the sediment weight over the total weight (sediment weight plus water weight). SSC will be analyzed via analysis of covariance with the model:

$$y_i = \beta_0 + \beta_1 x_{1i} + \beta_2 x_{2i} + \alpha_{j(i)} + \gamma_{k(i)} + \delta_{l(i)} + \beta\alpha_{1j(i)} x_{1i} + \beta\gamma_{1k(i)} x_{1i} + \beta\delta_{1l(i)} x_{1i} + \varepsilon_i$$

where

y_i	Natural log of SSC in bottle *i*
β_0	Intercept
β_1	The partial slope associated with days since December 1
x_{1i}	The number of days after December 1 when sediment was collected from bottle *i*
β_2	The partial slope associated with days since last rainfall
x_{2i}	The number of days since the previous rainfall
α_j	Effect of rainfall level j and j*(i)* is the level j associated with bottle *i*
γ_k	Effect of fertilizer level *k* and *k(i)* is the level *k* for bottle *i*
δ_l	Effect of treatment level *l* and *l(i)* is the level *l* for bottle *i*

$\beta\alpha$ Interaction between rainfall level *j* and time

$\beta\gamma$ Interaction between rainfall level *k* and time

$\beta\delta$ Interaction between fertilizer level *l* and time

ε_i Error term, assumed normal

Natural log of SSC is used because it results in an approximately linear relationship between time (measured in days since December 1, 2000) and the response variable and also results in approximately normal error terms.

Total runoff (in grams) will be also be analyzed via analysis of covariance:

$$y_i = \beta_0 + \beta_1 x_{1i} + \beta_2 x_{2i} + \alpha_{j(i)} + \gamma_{k(i)} + \delta_{l(i)} + \beta\alpha_{2j(i)} x_{2i} + \beta\gamma_{2k(i)} x_{2i} + \beta\delta_{2l(i)} x_{2i} + \varepsilon_i$$

where

y_i Square root of total runoff in bottle *i*

β_0 Intercept

β_1 The partial slope associated with days since December 1

x_{1i} The number of days after December 1 when sediment was collected from bottle *i*

β_2 The partial slope associated with days since last rainfall

x_2 The number of days since the previous rainfall

α_j Effect of rainfall level j and j*(i)* is the level j associated with bottle *i*

γ_k Effect of fertilizer level *k* and *k(i)* is the level *k* for bottle *i*

δ_l Effect of treatment level *l* and *l(i)* is the level *l* for bottle *i*

$\beta\alpha$ Interaction between rainfall level *j* and time since last rainfall

$\beta\gamma$	Interaction between rainfall level *k* and time since last rainfall
$\beta\delta$	Interaction between fertilizer level *l* and time since last rainfall
ε_i	Error term, assumed normal

Square root of total runoff is used because it results in an approximately linear relationship between time (measured in days since last precipitation) and the response variable and also results in approximately normal error terms.

Sediment runoff (in grams) will be similarly be analyzed via analysis of covariance:

$$y_i = \beta_0 + \beta_1 x_{1i} + \beta_2 x_{2i} + \alpha_{j(i)} + \gamma_{k(i)} + \delta_{l(i)} + \varepsilon_i$$

where

y_i	=	Square root of sediment in bottle *i*
β_0	=	Intercept
β_1	=	The partial slope associated with days since December 1
x_{1i}	=	The number of days after December 1 when sediment was collected from bottle *i*
β_{2i}	=	The partial slope associated with days since last rainfall
x_{2i}	=	The number of days since the previous rainfall
$\alpha_{j(i)}$	=	Effect of rainfall level j and j*(i)* is the level j associated with bottle *i*
$\gamma_{k(i)}$	=	Effect of fertilizer level *k* and *k(i)* is the level *k* for bottle *i*
$\delta_{l(i)}$	=	Effect of treatment level *l* and *l(i)* is the level *l* for bottle *i*
ε_i	=	Error term, assumed normal

Square root of sediment runoff is used because it results in an approximately linear relationship between time (measured in days since last precipitation) and the response variable and also results in approximately normal error terms.

8. RESULTS AND DISCUSSION

General Summary

- This experiment, while it does allow us to spot treatments or rainfall regimes that lead to higher vegetation cover or lower runoff does not allow us to fully explain why these treatments have these effects.
- Furthermore, it is not clear that high vegetation cover is necessarily a desired outcome. In particular, if the cover is composed of primarily weedy non-natives, high cover may be less desirable than lower cover made up of seeded plants.
- Our results are confounded with microclimate effects in a way that cannot be completely controlled.

Summary of Runoff and Sediment Production

- High and medium rain regimes produced higher vegetation cover in the understory than low and natural rainfall.
- Fertilizer appears to increase proportion vegetation cover in boxes with high and medium rainfall levels in the understory. This occurs in the overstory as well, but the effect is less significant.
- Fertilized boxes have more sediment in the runoff than unfertilized boxes.
- Boxes with straw have lower sediment in the runoff than boxes with tackifier.
- SSC decreases with time.

Summary of Vegetation Cover

- Treatment box vegetation was composed of mostly non-native species present in the non-sterilized soil typical of most roadsides
- Over all 32 boxes, 45 species were observed: 10 were members of the seed mix, 35 were not
- Annual Ryegrass (Lolium multiflorum), an alien non-seeded species, constituted 64% absolute cover (plants + non-vegetated soil) and 70% relative cover (plants only) overall
- Of the seeded species, grasses and forbs exhibited greater establishment than shrubs did
- California Brome (Bromus carinatus) at ≈ 15%, and Arroyo Lupine (Lupinus succulentus), at ≈ 5.5%, were most evident in the overstory
- California Poppy (Eschscholzia californica) at ≈ 14%, White Yarrow (Achillea millefolium) at ≈ 8%, and Small Fescue (Festuca microstachys) at ≈ 4%, were most evident in the understory

- California Sagebrush (Artemisia californica) was the only seeded shrub to emerge with any success at about 1.4% cover and 216 total seedlings counted, mostly under average to high rainfall simulation
- No sagebrush seedlings were observed among any of the boxes that received natural rain even though the total precipitation for the season was just above the 50-year average.

WATER QUALITY TRENDS

The following figures illustrate the results between the four treatments and the total sediment or SSC produced for simulated and natural rainfall. These figures represent the average numbers over the entire simulated rainfall experiment or the average for all the natural rainfall boxes and an average for the natural/unseeded boxes over the five day rainfall period. These numbers represent the average and therefore a possible trends in the data over the entire experiment and not the results from the statistical analysis performed in the results and discussion section of this report. These figures are used for general observations and to view a possible trend that could be further studied in future experiments at the erosion facility and in the field.

The legend for the figures on the X-axis is below. An X indicates the absence of the treatment with fertilizer as F, Straw as S, and tackifier as T. The Y-axis is the yield of sediment as either grams or grams/ml.

1	fiber:compost, seed, and crimped straw -	XSX
2	fiber:compost, seed, and tackifier -	XXT
3	fiber:compost, seed, fertilizer, and crimped straw -	FSX
4	fiber:compost, seed, fertilizer, and tackifier, -	FXT

The **SSC** was calculated by taking the sediment divided by water amount in container plus sediment.

8.1.1 Simulated Rainfall Boxes

Figure 7.1 represents the average total grams of sediment for each of the treatments. The high simulated rainfall pattern created more sediment and the fertilizer and tackifier tended to produce the most sediment while the straw treatment alone produced the least amount of sediment. The medium rainfall pattern had the fertilizer and straw and the tackifier alone produce the least amount of sediment. The low rainfall had the straw alone produce the most amount of sediment.

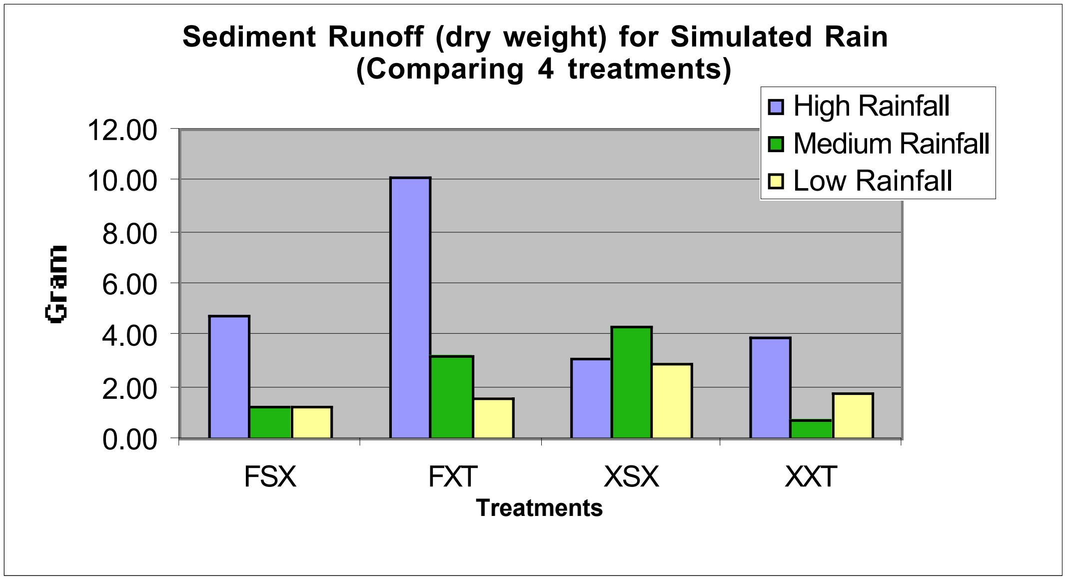


Figure 7.1. The average total sediment for the treatments in the simulated rainfall boxes.

Figure 7.2 is the average total SSC for the three rainfall patterns and four treatments. This figure shows that the low rainfall pattern produced more sediment per volume of water with the straw and tackifier treatment alone having slightly lower concentrations. The high rainfall with fertilizer and tackifier produced the most amount of sediment and straw alone produced the least amount. The medium rainfall had the straw alone produce the most amount of sediment and the fertilizer and tackifier produced the least.

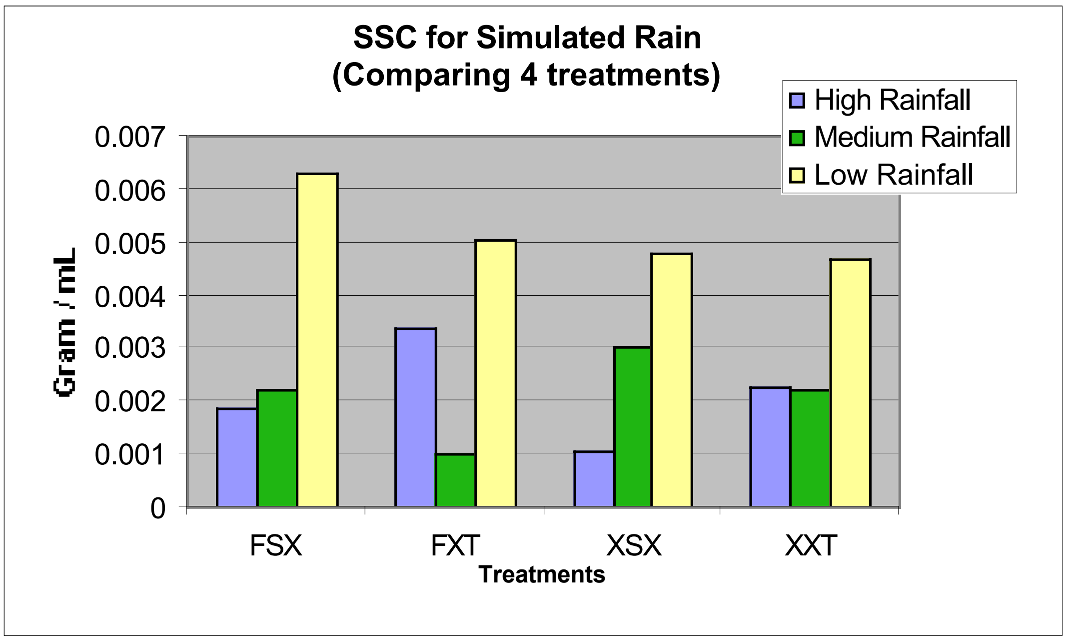


Figure 7.2. The average SSC for the treatments in the simulated rainfall boxes.

8.1.2 Natural Rainfall Boxes

Figure 7.3 represents the average total sediment produced per ml of runoff for the entire natural rainfall season. The fertilizer and straw treatments appear to produce less total sediment over the season. The fertilizer and tackifier treatment produced the most SSC.

Figure 7.4 is the average total sediment produced for the natural rainfall boxes over the entire season. The fertilizer and tackifier boxes produced the most total average sediment. The straw alone produced the least sediment.

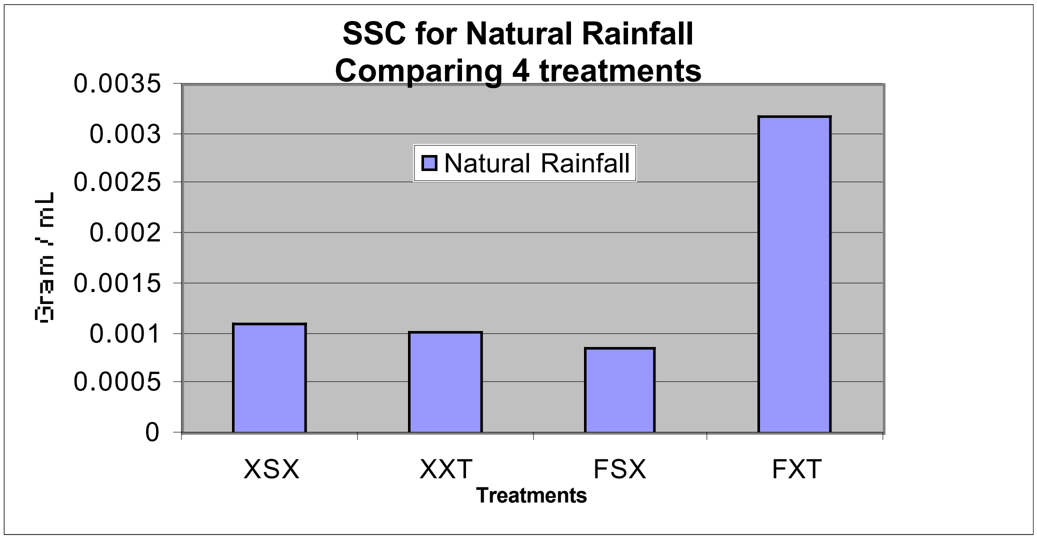


Figure 7.3. The average SSC for the natural rainfall boxes

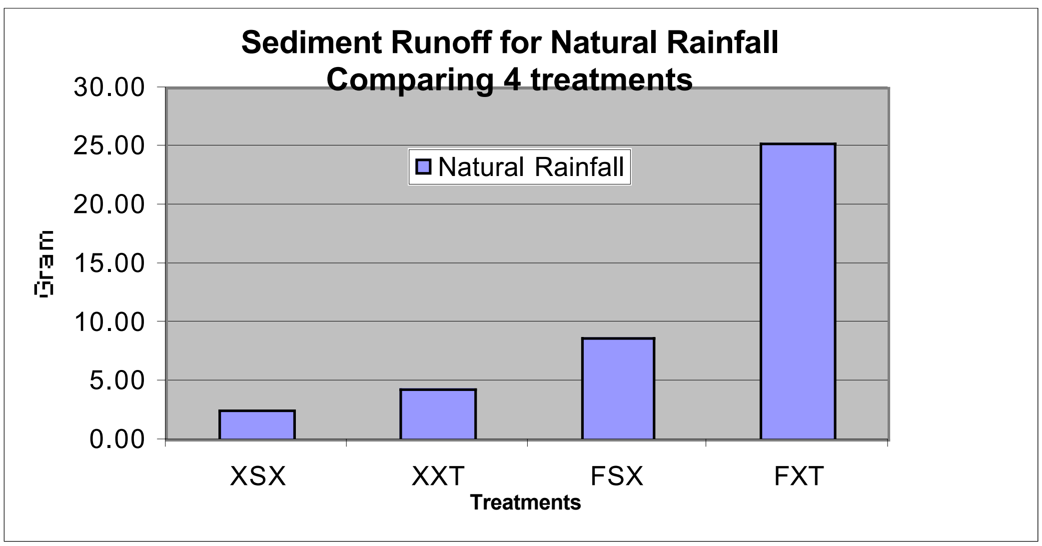


Figure 7.4. The average total sediment for the natural rainfall boxes.

8.1.3 Bare and unseeded rainfall boxes

Over a 5-day period, we ran 2 different types of control boxes. The first set of boxes were packed with the original boxes but did not have any treatments. Therefore they were bare and idle for the spring and summer months. Natural rainfall and the natural seeds that were existing in the soil. These boxes were to simulate a project being completed in the spring with rainfall and the existing seed bank. The second set of boxes were also packed with the original boxes without treatments. These boxes were repacked immediately with the same soil to simulate a project that was just completed and the soil was left bare.

Over a 5-day period, two rainfall patterns were tested. (high = 2" and low = 1" per day) An average was taken for each treatment.

Figure 7.5 represents the average total sediment produced for the bare and unseeded soil boxes under high and low simulated rainfall patterns. The bare soil boxes appear to produce more total sediment when compared to the unseeded boxes with the high rainfall boxes producing more total sediment. The total sediment production for the bare soil boxes under high simulated rainfall patterns appeared to remain relative high for the 5 day period.

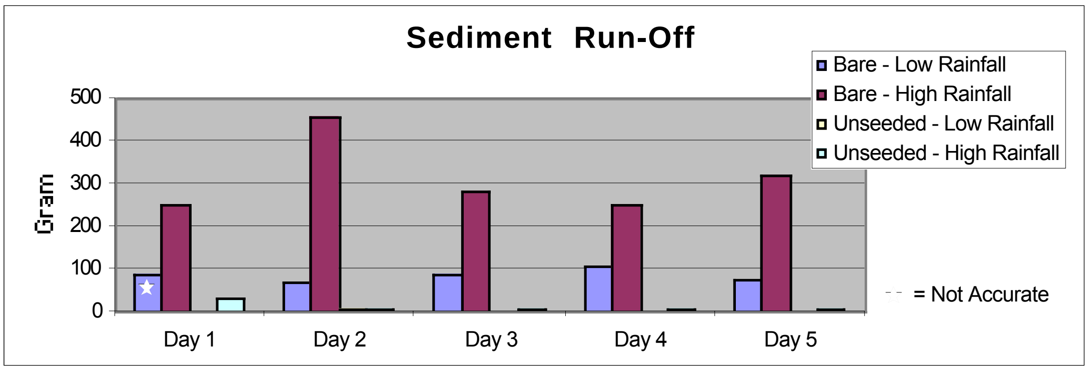


Figure 7.5. The average total sediment for the bare and unseeded boxes over a 5 day simulated rain pattern of high and low rainfall.

Figure 7.6 represents the average SSC calculated for each simulated rainfall pattern over a five day sequence. Even though the unseeded produced only a small amount of total sediment, the grams/ml was the highest on the first day and then quickly decreased. The bare soil boxes increased in day two and then dropped off to just below the first day for the remainder of the five day simulated rainfall pattern.

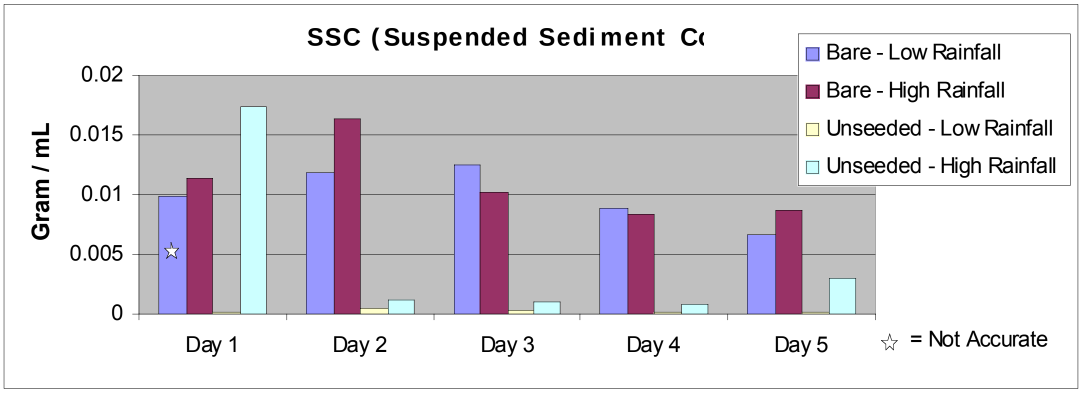


Figure 7.6. The average total SSC calculated for the bare and unseeded boxes over a 5 day simulated rainfall pattern of high and low rainfall.

ESTIMATION OF VEGETATION COVER

Overall, vegetation present in the treatment boxes consisted largely of non-native species present in the non-sterilized soil purchased for this experiment. This mimics typical soil seed bank conditions present along most roadsides under Caltrans management, especially within District 5. In total, 45 species were observed including 10 intentionally seeded, and 35 not seeded but present in the soil. Four of the species intentionally seeded were not observed anywhere in any box. A breakdown of species numbers by life form is presented at right. Annual Ryegrass (*Lolium multiflorum*) constituted 64% absolute cover (plants + non-vegetated soil) and 70% relative cover (plants only) overall. As noted above, these values are likely underestimates. Notable also is that an estimated 9% of the surface among boxes was not vegetated at all, and an estimated 51% of the understory was not vegetated either. This indicates that other measures (e.g., mulch, compost, straw, tackifier) would be necessary to achieve 100% cover of the soil surface and reduce effects from raindrop impacts.

Species Present in Vegetation

Lifeform	Seeded	Not-Seeded
Annual Forbs	3	19
Perennial forbs	1	7
Annual Grasses	1	9
Perennial Grasses	2	0
Shrub Seedlings	3	0

Of the species used in the seed mix, five were of notable presence in the overall vegetation. In the overstory, California Brome (*Bromus carinatus*) at ≈ 15%, and Arroyo Lupine (*Lupinus succulentus*), at ≈ 5.5%, made reasonable showings. California Poppy (*Eschscholzia californica*) at ≈ 14%, White Yarrow (*Achillea millefolium*) at ≈ 8%, and Small Fescue (*Festuca microstachys*) at ≈ 4%, were most evident in the understory at cover values not unlike local native stands. California Sagebrush (*Artemisia californica*) was the only seeded shrub to emerge with any success at about 1.4% cover and 216 total seedlings counted; 178 of these occurred among only 8 of the 32 treatment boxes under average to high rainfall simulation. Notably no sagebrush seedlings were observed among any of the boxes that received natural rain even though the total precipitation for the season was just above the 50-year average.

Summary tables listing the number of hits, and percentages of absolute and relative cover, are presented in **Appendix 1** for overstory and understory vegetation across all treatments combined.

Two important issues must be considered when evaluating the summary tables. First, is the probable underestimation of total and individual species' cover values. Because we arbitrarily divided the complex, three-dimensional vegetation into two layers and recorded only a single "hit" for overstory or understory at each point position, potential "hits" upon other parts of the same plant, or on different plants, as the pin passed down through the layered vegetation were not scored. Scoring all possible "hits" at each pin position is extremely tedious and time-consuming, so we chose to limit our scoring to the two obvious layers: a taller overstory of mostly grasses; and a shorter understory of annual grasses, annual forbs, perennial forb seedlings, and shrub seedlings.

Second, is that cover values of zero reflect scored positions only and not the totality of the vegetation. Cover values stated are only estimates of true population values. In our case, however, the totality of our two-dimensional box space is only 416 square feet. Thus, values of zero for "hits", absolute cover, and relative cover are very likely real.

STATISTICAL ANALYSIS –

Preliminary analyses suggest that the role of shade may not be statistically significant if box-division is included in our model. This seems to be largely because the lower box-half is usually what is shaded and the few boxes where there is no shading in the lower box-half aren't presenting strong evidence of higher proportional cover.

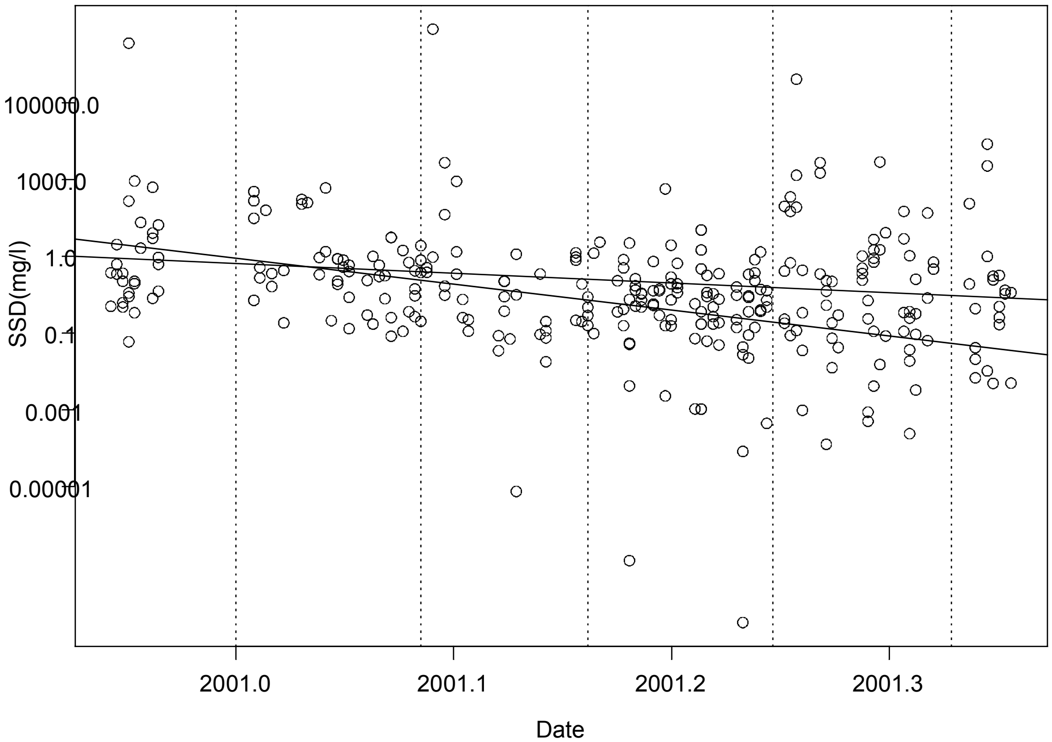
The different locations where the boxes are may have different microclimates, which could cause a difference in proportion cover. Further analyses needs to include block effects in the model that could allow for us to estimate the microclimate effect. Such effects will likely be confounded with rainfall regime due to the non-random location of the boxes.

8.1.4 Water Quality

8.1.4.1 SSC

See Minitab output in section 8.2.1 of Appendix I.

- Design storm 1 does not have statistically lower log SSC than Design storm 2 at the start of our simulations (well, at least according to our estimates of what log SSC would have been on December 1). Days since December 1 fits slightly better. The log of SSC decreases by approximately 0.01323 for each day after December 1 for design storm 2.
- The log of SSC decreases by approximately 0.00794 each data for design storm 1.
- Days since last precip doesn't affect log SSC in a statistically significantly way (note: total previous precipitation doesn't affect log SSC either. An earlier model showed that date itself was a far better predictor of log SSC than total previous precip)
- Rainfall regime, Fertilizer and treatment (straw versus tackifier) don't effect log SSC in a statistically significant way, either at the start of the experiment or over time.
- SSC approximately follows the following graph as a function of time (see reduced model in section 8.2.1.1):

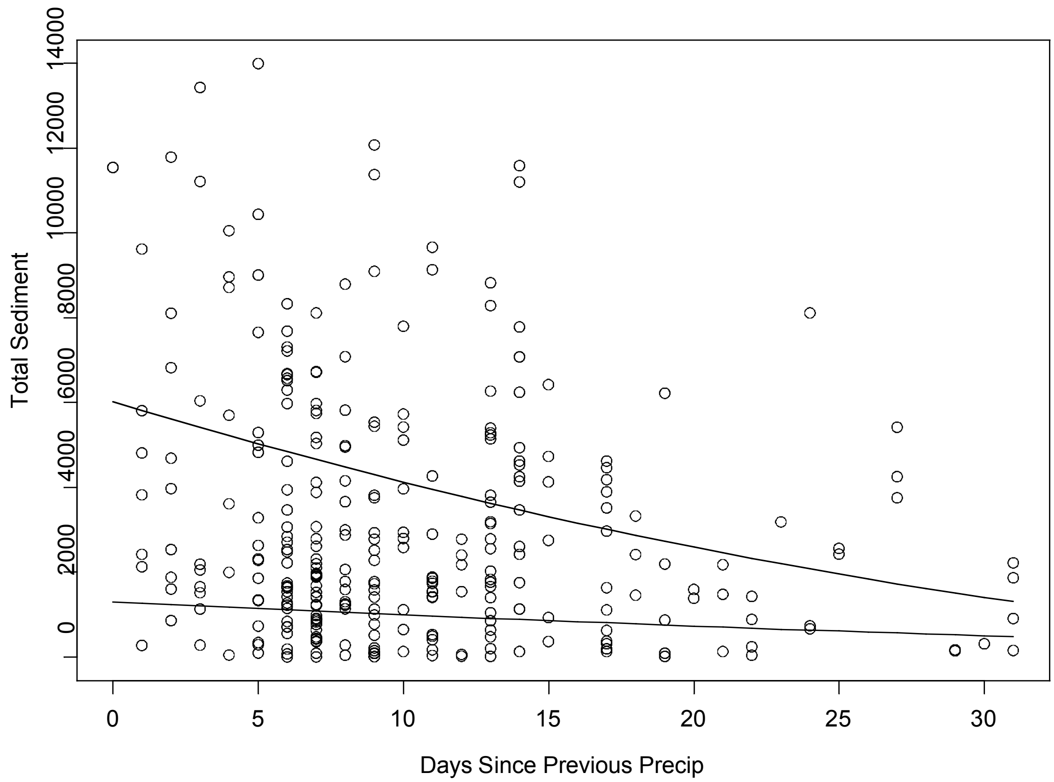


8.1.4.2 Total Runoff

While SSC seems to largely depend on the design storm and time since hydroseeding, the total runoff (the denominator in the SSC calculation) depends largely on days since the last precipitation and the design storm.

- For design storm 2 the root of total runoff decreases by 0.6155 for each day since the previous precipitation.

- For design storm 1 the root of total runoff doesn't change with days since previous precipitation.
- Total Runoff approximately follows the lines on the following graph:



8.1.4.3 Total Sediment in Runoff

Total sediment in the runoff depends on the number of days since December 1, 2000, the design storm, the rainfall regime, and the use of fertilizer and treatment (straw versus tackifier).

- The root of total sediment decreases by 0.0065 with each day since December 1, 2000.
- The root of sediment is smaller with design storm 1 than with design storm 2.
- High rainfall regime tends to have more sediment in each individual rainfall event than medium or low rainfall (Note: this could very well be because the soil isn't dried out before the next rainfall … this is much like the days since the previous rainfall variable).
- Fertilized boxes have higher runoff than unfertilized boxes.
- Boxes with straw have lower runoff than boxes with tackifier.

8.1.5 Vegetation Cover

8.1.5.1 Overstory

For the overstory, it is worth noting that only two boxes (31 and 20) had lower than 80% cover. One implication of this is that it will be difficult to determine which factors (if any) are related to high cover because they all seem to result in high cover.

For this discussion we will be referring to the logistic regression model (note: all models produce similar results) for parameter estimation and the arcsine root model for multiple comparisons.

Logistic Regression

For the overstory, all the low rainfall level results for the lower box division resulted in 100% coverage of the sampled points, so logistic regression cannot estimate the parameters corresponding to either the low rainfall level or the low rainfall level lower box division interaction. The criterion SPSS uses for determining the maximum likelihood in such situations is relative function convergence (see output in Appendix I). Even though these two terms cannot be estimated, the difference between the two can be estimated precisely and is by SPSS.

Significant factors include rainfall regime, a rainfall by treatment (straw versus tackifier) interaction and a rainfall by fertilizer interaction. The apparently significant rainfall effect and rainfall by fertilizer interaction seem to largely be due to box 31 (which received medium rain) having a low level of cover. Removing this one box from the analysis eliminates the significance of the rainfall factor and the rainfall by straw interaction.

The one lesson we can draw from these data is that no fertilizer with high rain produces less cover in the overstory than fertilizer in the high rain boxes.

A likely explanation for greater overstory cover with the combination of high rain and fertilizer is the known positive response to added nitrogen by Annual Ryegrass up to levels of about 448kg (400lbs) N per acre (Hannaway et al. 1999; Riewe and Mondart 1985). Because Annual Ryegrass constituted the majority of total plant cover, the added nitrogen likely enhanced the growth response by this annual grass and resulted in larger plants with more leaf area. The high rain regime likely increased solubility of the granular fertilizer and made more nitrogen available for plant uptake overall, and especially by Annual Ryegrass.

The Hosmer-Lemeshow goodness of fit test suggests a distinct lack of fit of the data to our model. This lack of fit is due entirely to box 31. Without that one box in the analysis the Hosmer-Lemeshow test indicates adequate fit.

Multiple Comparisons

One might naturally want to know which treatment is best for any particular rainfall pattern. To address this question we performed a post-hoc comparison of the four fertilizer by treatment combinations (straw without fertilizer, tackifier without fertilizer, straw with fertilizer and tackifier with fertilizer). This gives 24 comparisons (six comparisons between these four groups for each of the 4 rainfall regimes) for each the overstory and understory. We will also be averaging across both box-divisions for the comparisons. Using Bonferroni post-hoc comparisons (with experiment-wide error rate 5%, i.e. we are 95% sure that *all* the comparisons we are making are correctly bracketing the true difference between treatments) on the arcsine root ANOVA we conclude that there is not a statistically significant difference in the overstory percent cover between any treatments for any rainfall levels.

It is worth noting that with a larger number of replicates (or a smaller number of comparisons) we would be more likely to spot differences between the treatments should any exist.

8.1.5.2 Understory

As with the overstory, we will again in this discussion be using logistic regression for our discussion of parameter estimates but using the arcsine root ANOVA model for multiple comparisons.

Logistic Regression

According to the logistic regression output for the understory (see section in Appendix I) the proportion cover in the understory depends on rainfall, fertilizer, straw (versus tackifier) and even which box-division we are considering. In particular, there is a rainfall effect, a rainfall fertilizer interaction, rainfall treatment interaction, rainfall box-division interaction, fertilizer treatment interaction, fertilizer box-division interaction and a treatment box-division interaction. This tells us that the percent cover in the understory is affected by rainfall (but differently in the lower and upper box-divisions), and that the effect of fertilizer on percent cover differs by rainfall regime, whether straw or tackifier is used and even box-division.

Additionally, the effect of straw versus tackifier differs by rainfall regime and box-division. We summarize these results:

- Fertilizer is more effective at producing cover in the understory than no fertilizer with medium and high rainfall but this is not necessarily the case for low and natural rainfall. This suggests a typical plant growth response curve where low water availability is initially more limiting to plant growth than is low nutrient availability because seed endosperm reserves provide adequate nutrients for germination and initial growth. Under high and medium rain regimes, water is readily available for photosynthesis and other plant needs. At these higher rain levels added nutrients in the form of fertilizer then promote development of more and larger roots, stems, and leaves. Inherent genetic control, along with infraspecific and interspecific competition for nutrients among individual plants, then ultimately limits plants size and overall cover.

- These data suggest that the effect of straw on understory cover depends on the rainfall level with medium and high rainfall having approximately the same proportion cover but low and natural rainfall having lower cover when there is no straw. A possible interpretation of these interactions is that straw is functioning to impede water runoff and allow slower penetration, thus increasing water availability and providing different microsite conditions for seeds and seedlings. The understory species in these shallow soil boxes likely experienced pronounced competition for water, light, and nutrients from rapidly growing overstory species, especially with the amount of Annual Ryegrass present. At the low and natural rain levels such competition would have been exacerbated, thus leading to poorer understory development.
- For natural rainfall, the box division (upper versus lower) makes no difference on proportion cover but for low, medium and high rainfall levels the upper box division has a higher proportion cover. For the upper box division medium rainfall produces more cover than high which beats low which beats natural.
- For the straw and fertilizer lower box halves, medium rain nets a greater proportion cover than high rain which beats low rain which beats natural.

These interactions among rain regime, box half, and presence of straw and fertilizer are obviously complex with no definitive result. Higher cover values in the upper box halves for rain regimes other than natural may indicate possible differences in soil water content, soil temperature related to water content, or shading. The overall reduced response in the natural boxes is likely attributable to the very erratic and inconsistent precipitation regime peculiar to the last rain season. Overstory growth in these boxes was substantially reduced when compared with the medium boxes despite both receiving approximately the same seasonal total. Not surprisingly, understory growth was extremely poor owing to poor germination and establishment in competition with even the reduced overstory cover of Annual Ryegrass in the natural boxes.

The higher overall plant cover for medium rain boxes, both in box half differences and in the presence of straw and fertilizer in the lower half, suggests that experimental logistics and execution may be an unaccounted for source of variation. Because the simulated boxes had to be shielded from natural rainfall during storm events, tarps were placed over these boxes as temporary cover. As the rain season progressed, high rain boxes were receiving simulated storms about every week or 10 days. Perhaps this added water in conjunction with the colder temperatures and higher humidity values experienced during the winter promoted cold and wet soil conditions less conducive to plant germination and growth than present among the medium rain boxes given more time to dry and warm between rain events.

Given the absence of soil temperature and moisture data, we are only able to offer ad hoc speculations about these interactions.

Multiple Comparisons

For the understory percent cover with a high rainfall level, fertilizer and tackifier nets a higher percent cover than straw alone. If we adopt a 10% experiment-wide error rate, we would also conclude that fertilizer and tackifier is better than tackifier alone.

For the understory percent cover with medium rainfall, fertilizer and straw is preferable to straw alone. If we adopt a 10% experiment-wide error rate, we would also conclude that fertilizer and straw beat tackifier alone.

9. QUALITY ASSURANCE/CONTROL

Norton Rainfall Simulator Calibration

Understanding the limitations of the Norton rainfall simulators and their calibration began on June 28, 2000. The simulators were suspended from an existing framework using ropes and a grid was painted on the concrete slab below to coordinate the placement of 6-inch diameter steel cans for collection of the simulated rainfall. The simulators were initially set to a nozzle pressure of 6 psi. The simulators were run for 30 minutes. The volume of water in the cans was measured and recorded in a laboratory notebook. Several experiments were conducted to verify repeatability. The simulators were then tested separately, in the likely event the overlap between simulators would be difficult to uniformly calibrate. The coefficient of uniformity was used to determine uniformity of the rainfall applied by the simulators

On July 11, 2000 we began to incorporate sweeps per minute into the uniformity tests. At this time also we began to reduce the size of the critical area beneath the simulator. This was accomplished by measuring the area beneath the simulator where the application of rainfall seemed consistent in volume. It was determined at this time it would only be possible to have uniform rainfall for one erosion test box under each simulator.

On August 15, 2000 two empty boxes, each with 48, steel cans were placed under the simulators. The position of the boxes was recorded in the laboratory notebook. The boxes were supported at a 2:1 slope using the stands designed for use with the boxes. The simulators were supported using a chain hoist at the same slope.

After each rainfall simulation the volume of water in each can was measured and recorded. These numbers were then used in calculating the coefficient of uniformity equation. Coefficient of uniformity measured for each box was slightly greater than 80 percent (82.2% for sim 1, 81.6% for sim 2). We began looking at ways to improve upon the existing setup, in particular, the box placement beneath each simulator.

Several more tests were performed prior to moving the edge of the box contacting the concrete 35 inches from the edge of the concrete directly in front of it. On August 16, 2000 the simulators were moved back away from the headhouse and the boxes were moved to a location 43 inches away from the edge of the concrete. The distance between the inside rails of the simulators was measured to be 27 inches.

On August 17, 2000 only the bottom two nozzles on each simulator were used for calibration. The swaths of the two nozzles were sufficient to cover the length of the box. The inside edge of the soil erosion test boxes were measured at 22.5 inches and the leading edge of the box was 69 inches away from the edge of the concrete. The upper two nozzles on each simulator were blocked off.

To reduce overlap of spray from the simulators, the soil erosion test boxes were moved an additional 4 inches apart.

On August 19, 2000 tests were performed using 3 out of the 4 nozzles leaving the uppermost nozzle on each simulator blocked off. Soil erosion test boxes were moved to 93 inches away from the edge of the concrete. The simulators were 27 inches apart when measured from the inside frame rails.

A problem was experienced as we noted in our measurement simulator # 2 applying more water to the erosion test box beneath it than simulator 1. The nozzles on simulator # 2 were swapped with the nozzles on simulator # 1 to rule out any possible inconsistencies between simulators in regard to emitters. The nozzles on each simulator were examined in order to be certain the openings were parallel to the rainfall pattern openings on the simulators. We also began experimenting with the hose lengths, both from the manifold to the simulator and from the pump to the manifold. All hose lengths were cut to equal lengths for both simulators.

Some fine-tuning of the simulators was required. It was our objective to have both simulators operating as identically as possible. We noticed the sweep pattern of each simulator to be slightly different than its counterpart. The cam on the simulator actuating the nozzle shaft was synchronized for both simulators so that the nozzles have the same degree of travel on each sweep for both simulators.

September 1, 2000 was the date of the first test with the 2 control valve manifolds between the pump and the simulator. A control manifold for each simulator was fabricated. Coefficient of uniformity measured on simulator 1 = .89, simulator 2 = .92.

Simulations were performed throughout the month of September to ensure a uniformity of both simulators greater than .9 was maintained.

9.1.1 Rainfall simulator uniformity

In order to be sure the Norton rainfall simulators were consistently applying the proper amount of rainfall for a given storm event, we ensured uniformity about once a month. The test to check uniformity was performed using two empty erosion test boxes and filling each of the boxes with 48 six inch cans. After assuring the support stands and erosion test boxes filled with cans were in the proper place, all of the steps were completed in the same fashion for doing a real simulation. The results of a two hour, one inch storm test completed on April 3, 2001 is found below.

Simulator 1				Simulator 2			
407	444	438	450	390	441	460	466
447	478	475	477	427	484	500	511
440	478	488	478	441	501	530	525
439	475	475	490	461	511	530	502
409	413	474	435	417	435	495	437
383	394	380	425	432	455	420	470
397	407	438	409	430	440	480	470
393	412	400	415	395	423	438	445
401	426	431	435	388	420	455	460
407	420	433	425	415	430	450	447
376	397	415	405	385	407	440	435
378	404	410	419	420	450	445	463

Each value was measured in milliliters. The mean for all of the values for each simulator was calculated and the amount each value deviated from the mean was added and used to determine the coefficient of uniformity for each simulator. The mean for this test for simulator 1 was 427. 979 ml. The mean for simulator 2 was 451.562. Coefficient of uniformity measured for simulator 1 was 93.9% while simulator 2 was 93.6%. This is important to the project because we are not interested in having one area of the box biased with significantly more or less rainfall than the mean.

These uniformity tests were generally performed in cooperating weather. Several times uniformity tests were performed during noticeably breezy conditions. The data collected and processed during these windstorms indicated that these conditions have a detrimental effect on uniformity. Simulations were put on hold because the wind has a greater effect on the uniformity of rainfall than any other factor.

QA/QC - STATISTICS

Statistical calculations were carried out in three separate statistical packages, Minitab (version 12), SPSS (version 9.0) and S-Plus (2000). In some cases the algorithms used by each package differ (for example, the stopping rule for logistic regression differs in SPSS and Minitab), but the results do not differ across statistical package.

QA/QC – NATURAL RAINFALL

The 75.6 L (20 gal) bins may have been too much for the size of sample collected. Surrounding trees often shed leaves onto the soil of the boxes. The leaves were picked off as soon as possible before rain and sediment would seal them into the soil surface. Also, the surrounding concrete slab was kept clean to reduce dust and leaves from flowing into the gutters and boxes.

10. REFERENCES

Agresti, Alan (1996) *An Introduction to Categorical Data Analysis*, John Wiley & Sons, New York

Agresti, Alan (1998) "Approximate is Better than Exact for Interval Estimation of Binomial Proportions", *American Statistician*.

Bonham, C.D. 1989. *Measurements for Terrestrial Vegetation*. New York: Wiley & Sons.

Cliff, A.D., and J.K. Ord. 1973. Spatial Autocorrelation. London: Pion.

Fortin, M.-J., P. Drapeau, and P. Legendre. 1989. Spatial autocorrelation and sampling design in plant ecology. *Vegetatio* 83: 209-222

Hannaway, D., S. Fransen, J.Cropper, M. Teel, M. Chaney, T. Griggs, R. Halse, J. Hart, P. Cheeke, D. Hansen, R. Klinger, and W. Lane. 1999. Annual Ryegrass (*Lolium multiflorum* Lam.). *Pacific Northwest Extension Publication* 501. Corvallis: Oregon State University. http://eesc.orst.edu/agcomwebfile/edmat/html/pnw/pnw501

Hickman, J.C. (ed.). 1993. *The Jepson Manual: Higher Plants of California*. Berkeley: University of California Press.

Interagency Technical Team. 1996. *Sampling Vegetation Attributes*. Bureau of Land Management National Applied Resource Sciences Center. USDI-BLM/RS/ST-96/002+1730

Kent, M., and P. Coker. 1992. *Vegetation Description and Analysis: A Practical Approach*. London: CRC Press.

Legendre, P. 1993. Spatial autocorrelation: trouble or new paradigm? Ecology 74: 1659-1673.

Montgomery, Douglas C., (1991) *Design And Analysis Of Experiments*, 3rd edition, John Wiley & Sons, New York

Mueller-Dombois, D., and H. Ellenberg. 1974. *Aims and Methods of Vegetation Ecology*. New York: John Wiley & Sons.

Riewe, M.E., and C.L. Mondart, Jr. 1985. The Ryegrasses. pp. 241-246. *In*: Heath, M.E., R.F. Barnes, and D.S. Metcalfe (eds.), *Forages: The Science of Grassland Agriculture*. ed. 4. Ames, IA: Iowa State University Press.

11. Appendix I – Statistical Results

Vegetation Cover Data

11.1.1 Cover of Seed Mix Species after 150 days for All Treatments Combined distinguishes species with recognizable presence in the vegetation among treatment boxes

Table 11.1 Seed Mix Cover after 150 days for all treatments.

				Overstory			Understory				
Vernacular Name	**Scientific Name**	**Family**	**LF**	**Hits**	**%AbsCov**	**%RelCov**	**Hits**	**%AbsCov**	**%RelCov**	**%PLS/Mix**	**PLS/ft2**
California Brome	***Bromus carinatus***	Poaceae	*Gp*	**479**	**14.97**	**16.46**	**7**	**0.22**	**0.45**	25.0	24
Arroyo Lupine	***Lupinus succulentus***	Fabaceae	*Fa*	**173**	**5.41**	**5.95**	**41**	**1.28**	**2.63**	5.0	1
White Yarrow	***Achillea millefolium***	Asteraceae	*Fp*	**7**	**0.22**	**0.24**	**256**	**8.00**	**16.40**	2.5	63
California Poppy	***Eschscholzia californica***	Papveraceae	*Fa*	**3**	**0.09**	**0.10**	**449**	**14.03**	**28.76**	5.0	13
Pin-Point Clover	***Trifolium gracilentum***	Fabaceae	*Fa*	**2**	**0.06**	**0.07**	**64**	**2.00**	**4.10**	12.5	58
Small Fescue	***Festuca microstachys***	Poaceae	*Ga*	0	0.00	0.00	**141**	**4.41**	**9.03**	2.5	23
California Sagebrush	***Artemisia californica***	Asteraceae	*S*	0	0.00	0.00	**21**	**0.66**	**1.35**	2.5	127
Coyote Bush	*Baccharis pilularis*	Asteraceae	*S*	0	0.00	0.00	3	0.09	0.19	2.5	116
Purple Needlegrass	*Nassella pulchra*	Poaceae	*Gp*	0	0.00	0.00	2	0.06	0.13	2.5	5
Black Sage	*Salvia mellifera*	Lamiaceae	*S*	0	0.00	0.00	1	0.03	0.06	2.5	14
Blue Wild Rye	*Elymus glaucus*	Poaceae	*Gp*	*0	0.00	0.00	*0	0.00	0.00	12.5	15
Foothill Needlegrass	*Nassella lepida*	Poaceae	*Gp*	*0	0.00	0.00	*0	0.00	0.00	5.0	15
California Buckwheat	*Eriogonum fasiculatum*	Polygonaceae	*S*	*0	0.00	0.00	*0	0.00	0.00	12.5	52
Deerweed	*Lotus scoparius*	Fabaceae	*S*	*0	0.00	0.00	*0	0.00	0.00	5.0	21

11.1.2 Overstory Vegetation Cover after 150 days for All Treatments Combined

Table 11.2 Overstory vegetation cover after 150 days.

Vernacular Name	Scientific Name	Family	LF	Origin	Hits	%AbsCov	%RelCov	%PLS/Mix	PLS/ft2
Annual Ryegrass	*Lolium multiflorum*	Poaceae	***Ga***	Alien	2043	**63.84**	**70.21**	ns	?
California Brome	***Bromus carinatus***	**Poaceae**	***Gp***	**Native**	**479**	**14.97**	**16.46**	**25.0**	**24**
Arroyo Lupine	***Lupinus succulentus***	**Fabaceae**	***Fa***	**Native**	**173**	**5.41**	**5.95**	**5.0**	**1**
Black Mustard	*Brassica nigra*	Brassicaceae	***Fa***	Alien	37	**1.16**	**1.27**	ns	?
Common Wild Oat	*Avena fatua*	Poaceae	***Ga***	Alien	28	**0.88**	**0.96**	ns	?
Pigweed	*Chenopodium murale*	Chenopodiaceae	***Fa***	Alien	27	**0.84**	**0.93**	ns	?
Field Mustard	*Brassica rapa*	Brassicaceae	***Fa***	Alien	22	**0.69**	**0.76**	ns	?
Tumble Mustard	*Sisymbrium altissimum*	Brassicaceae	***Fa***	Alien	21	**0.66**	**0.72**	ns	?
Common Vetch	*Vicia sativa*	Fabaceae	***Fa***	Alien	19	**0.59**	**0.65**	ns	?
Ripgut Brome	*Bromus diandrus*	Poaceae	***Ga***	Alien	15	**0.47**	**0.52**	ns	?
Yellow Sweet Clover	*Melilotus officianalis*	Fabaceae	***Fa***	Alien	14	**0.44**	**0.48**	ns	?
Milk Thistle	*Silybum marianum*	Asteraceae	***Fa***	Alien	10	**0.31**	**0.34**	ns	?
White Yarrow	***Achillea millefolium***	**Asteraceae**	***Fp***	**Native**	**7**	**0.22**	**0.24**	**2.5**	**63**
Poison Hemlock	*Conium maculatum*	Apiaceae	***Fp***	Alien	4	**0.13**	**0.14**	ns	?
California Poppy	***Eschscholzia californica***	**Papveraceae**	***Fa***	**Native**	**3**	**0.09**	**0.10**	**5.0**	**13**
Pin-Point Clover	***Trifolium gracilentum***	**Fabaceae**	***Fa***	**Native**	**2**	**0.06**	**0.07**	**12.5**	**58**
Soft Chess	*Bromus hordeaceus*	Poaceae	***Ga***	Alien	2	**0.06**	**0.07**	ns	?
Bur Clover	*Medicago polymorpha*	Fabaceae	***Fa***	Alien	1	**0.03**	**0.03**	ns	?
Wall Barley	*Hordeum murinum*	Poaceae	***Ga***	Alien	1	**0.03**	**0.03**	ns	?
Spanish Brome	*Bromus madritensis*	Poaceae	***Ga***	Alien	1	**0.03**	**0.03**	ns	?
Rattail Fescue	*Festuca myuros*	Poaceae	***Ga***	Alien	1	**0.03**	**0.03**	ns	?
No Vegetation					290	**9.06**	N/A		
					3200	**100.00**	**100.00**		

LF = lifeform (***Fa*** = Annual Forb; ***Fp*** = Perennial Forb; ***Ga*** = Annual Grass; ***Gp*** = Perennial Grass; **S** = Shrub)
Mix = whether species was intentionally seeded onto soil boxes
Hits = number of times species was encountered by a pin; ***** = species was not observed anywhere in any box
%AbsCov = (number of hits / 3200) x 100; includes hits for both vegetation and no vegetation (surface mulch layer)
%RelCov = (number of hits / 2910) x 100; includes hits for vegetation only
%PLS/Mix = percent of total pure live seed applied to each treatment box; ns = not seeded (present in purchased soil)
PLS/ft2 = seeding rate per square foot of pure live seed applied to each treatment box; ? = unknown quantity for spp. ns

11.1.3 Understory Vegetation Cover after 150 days for All Treatments Combined

Table 11.3 Understory vegetation cover after 150 days.

Vernacular Name	Scientific Name	Family	LF	Origin	Hits	%AbsCov	%RelCov	%PLS/Mix	PLS/ft2
California Poppy	***Eschscholzia californica***	**Papveraceae**	***Fa***	**Native**	**449**	**14.03**	**28.76**	**5.0**	**13**
White Yarrow	***Achillea millefolium***	**Asteraceae**	***Fp***	**Native**	**256**	**8.00**	**16.40**	**2.5**	**63**
Bur Clover	*Medicago polymorpha*	Fabaceae	***Fa***	Alien	197	**6.16**	**12.62**	ns	?
Small Fescue	***Festuca microstachys***	**Poaceae**	***Ga***	**Native**	**141**	**4.41**	**9.03**	**2.5**	**23**
Common Vetch	*Vicia sativa*	Fabaceae	***Fa***	Alien	105	**3.28**	**6.73**	ns	?
Common Knotweed	*Polygonum arenastrum*	Polygonaceae	***Fa***	Alien	83	**2.59**	**5.32**	ns	?
Pin-Point Clover	***Trifolium gracilentum***	**Fabaceae**	***Fa***	**Native**	**64**	**2.00**	**4.10**	**12.5**	**58**
Pigweed	*Chenopodium murale*	Chenopodiaceae	***Fa***	Alien	52	**1.63**	**3.33**	ns	?
Arroyo Lupine	***Lupinus succulentus***	**Fabaceae**	***Fa***	**Native**	**41**	**1.28**	**2.63**	**5.0**	**1**
Bristly Ox Tongue	*Pichris echioides*	Asteraceae	***Fa***	Alien	33	**1.03**	**2.11**	ns	?
California Sagebrush	***Artemisia californica***	**Asteraceae**	***S***	**Native**	**21**	**0.66**	**1.35**	**2.5**	**127**
Tumble Mustard	*Sisymbrium altissimum*	Brassicaceae	***Fa***	Alien	18	**0.56**	**1.15**	ns	?
Fennel	*Foeniculum vulgare*	Apiaceae	***Fp***	Alien	14	**0.44**	**0.90**	ns	?
Annual Ryegrass	*Lolium multiflorum*	Poaceae	***Ga***	Alien	12	**0.38**	**0.77**	ns	?
Bermuda Buttercup	*Oxalis pes-caprae*	Oxalidaceae	***Fp***	Alien	10	**0.31**	**0.64**	ns	?
Common Wild Oat	*Avena fatua*	Poaceae	***Ga***	Alien	9	**0.28**	**0.58**	ns	?
California Brome	***Bromus carinatus***	**Poaceae**	***Gp***	**Native**	**7**	**0.22**	**0.45**	**25.0**	**24**
Cheeseweed	*Malva parviflora*	Malvaceae	***Fa***	Alien	6	**0.19**	**0.38**	ns	?
Poison Hemlock	*Conium maculatum*	Apiaceae	***Fp***	Alien	5	**0.16**	**0.32**	ns	?
Black Mustard	*Brassica nigra*	Brassicaceae	***Fa***	Alien	4	**0.13**	**0.26**	ns	?
Smooth Cat's Ear	*Hypochaeris glabra*	Asteraceae	***Fa***	Alien	4	**0.13**	**0.26**	ns	?
Sow Thistle	*Sonchus oleraceus*	Asteraceae	***Fa***	Alien	4	**0.13**	**0.26**	ns	?
Wall Barley	*Hordeum murinum*	Poaceae	***Ga***	Alien	3	**0.09**	**0.19**	ns	?
Annual Bluegrass	*Poa annua*	Poaceae	***Ga***	Alien	3	**0.09**	**0.19**	ns	?
Coyote Bush	***Baccharis pilularis***	**Asteraceae**	***S***	**Native**	**3**	**0.09**	**0.19**	**2.5**	**116**
Milk Thistle	*Silybum marianum*	Asteraceae	***Fa***	Alien	2	**0.06**	**0.13**	ns	?
Common Dandelion	*Taraxacum officinalis*	Asteraceae	***Fp***	Alien	2	**0.06**	**0.13**	ns	?
Purple Needlegrass	***Nassella pulchra***	**Poaceae**	***Gp***	**Native**	**2**	**0.06**	**0.13**	**5.0**	**5**
Scarlet Pimpernel	*Anagallis arvensis*	Primulaceae	***Fa***	Alien	1	**0.03**	**0.06**	ns	?
Shepherd's Purse	*Capsella bursa-pastoris*	Brassicaceae	***Fa***	Alien	1	**0.03**	**0.06**	ns	?
Tansy Mustard	*Descurainia pinnata*	Brassicaceae	***Fa***	Native	1	**0.03**	**0.06**	ns	?
Red-Stem Filaree	*Erodium cicutarium*	Geraniaceae	***Fa***	Alien	1	**0.03**	**0.06**	ns	?
Yellow Sweet Clover	*Melilotus officianalis*	Fabaceae	***Fa***	Alien	1	**0.03**	**0.06**	ns	?
Purple Vetch	*Vicia benghalensis*	Fabaceae	***Fa***	Alien	1	**0.03**	**0.06**	ns	?
Mugwort	*Artemisia douglasiana*	Asteraceae	***Fp***	Native	1	**0.03**	**0.06**	ns	?
Curly Dock	*Rumex crispus*	Polygonaceae	***Fp***	Alien	1	**0.03**	**0.06**	ns	?
Salsify	*Tragopogon porrifolius*	Asteraceae	***Fp***	Alien	1	**0.03**	**0.06**	ns	?
Paradox Canarygrass	*Phalaris paradoxa*	Poaceae	***Ga***	Alien	1	**0.03**	**0.06**	ns	?
Black Sage	***Salvia mellifera***	**Lamiaceae**	***S***	**Native**	**1**	**0.03**	**0.06**	**2.5**	**14**
No Vegetation					1639	**51.22**	N/A		
					3200	**100.00**	**100.00**		

LF = lifeform (***Fa*** = Annual Forb; ***Fp*** = Perennial Forb; ***Ga*** = Annual Grass; ***Gp*** = Perennial Grass; **S** = Shrub)
Mix = whether species was intentionally seeded onto soil boxes
Hits = number of times species was encountered by a pin; * = species was not observed anywhere in any box
%AbsCov = (number of hits / 3200) x 100; includes hits for both vegetation and no vegetation (surface mulch layer)
%RelCov = (number of hits / 2910) x 100; includes hits for vegetation only

%PLS/Mix = percent of total pure live seed applied to each treatment box; ns = not seeded (present in purchased soil)
PLS/ft2 = seeding rate per square foot of pure live seed applied to each treatment box; ? = unknown quantity for spp. ns

Runoff Analyses

11.1.4 SSC

Minitab Output:

General Linear Model

```
Factor     Type Levels Values
Design S  fixed      2 1 2
Rainfall  fixed      3 H L M
Fertiliz  fixed      2 F X
Straw     fixed      2 S X

Analysis of Variance for root(Tot, using Adjusted SS for Tests

Source          DF     Seq SS     Adj SS     Adj MS       F      P
DSLP             1     7091.7     2777.8     2777.8    7.41  0.007
DSD1             1     2972.1      377.7      377.7    1.01  0.316
Design S         1    75806.4    27136.5    27136.5   72.41  0.000
Rainfall         2     6314.4     2211.3     1105.7    2.95  0.054
Fertiliz         1     1642.9      747.6      747.6    1.99  0.159
Straw            1     1136.5      731.4      731.4    1.95  0.163
Design S*DSLP    1     2060.3     2395.7     2395.7    6.39  0.012
Rainfall*DSLP    2      422.9      430.8      215.4    0.57  0.563
Fertiliz*DSLP    1       51.3       49.1       49.1    0.13  0.718
Straw*DSLP       1      132.7      132.7      132.7    0.35  0.552
Error          287   107558.3   107558.3      374.8
Total          299   205189.5

Term                 Coef     StDev         T       P
Constant           55.974     3.856     14.52   0.000
DSLP              -0.6155    0.2261     -2.72   0.007
DSD1             -0.02851   0.02840     -1.00   0.316
Design S
1                 -20.914     2.458     -8.51   0.000
Rainfall
H                   5.832     3.212      1.82   0.070
L                   1.579     4.045      0.39   0.697
Fertiliz
F                   3.066     2.171      1.41   0.159
Straw
S                  -3.026     2.166     -1.40   0.163
DSLP*Design S
     1             0.5833    0.2307      2.53   0.012
DSLP*Rainfall
     H             0.0130    0.2833      0.05   0.963
     L            -0.2839    0.3007     -0.94   0.346
DSLP*Fertiliz
     F            -0.0659    0.1820     -0.36   0.718
```

Note: `DSLP` is days since last precipitation and `DSD1` is days since December 1, 2000.

The model that has eliminated insignificant terms:

General Linear Model

```
Factor     Type Levels Values
Design S  fixed      2 1 2

Analysis of Variance for log(mg/l, using Adjusted SS for Tests

Source          DF     Seq SS     Adj SS     Adj MS       F      P
DSD1             1     45.009     69.572     69.572   29.20  0.000
Design S         1     23.274      2.620      2.620    1.10  0.295
Design S*DSD1    1     14.388     14.388     14.388    6.04  0.015
Error          296    705.272    705.272      2.383
Total          299    787.943

Term               Coef     StDev        T      P
Constant         1.2708    0.2339     5.43  0.000
DSD1          -0.012688  0.002348    -5.40  0.000
Design S
1               -0.2453    0.2339    -1.05  0.295
DSD1*Design S
     1         0.005770  0.002348     2.46  0.015
```

Note: DSD1 is days since December 1, 2000.

11.1.5 Total Runoff

Minitab output:

General Linear Model

```
Factor      Type Levels Values
Design S  fixed      2 1 2
Rainfall  fixed      3 H L M
Fertiliz  fixed      2 F X
Straw     fixed      2 S X

Analysis of Variance for root(Tot, using Adjusted SS for Tests

Source           DF     Seq SS     Adj SS     Adj MS       F      P
DSLP              1     7091.7     2777.8     2777.8    7.41  0.007
DSD1              1     2972.1      377.7      377.7    1.01  0.316
Design S          1    75806.4    27136.5    27136.5   72.41  0.000
Rainfall          2     6314.4     2211.3     1105.7    2.95  0.054
Fertiliz          1     1642.9      747.6      747.6    1.99  0.159
Straw             1     1136.5      731.4      731.4    1.95  0.163
Design S*DSLP     1     2060.3     2395.7     2395.7    6.39  0.012
Rainfall*DSLP     2      422.9      430.8      215.4    0.57  0.563
Fertiliz*DSLP     1       51.3       49.1       49.1    0.13  0.718
Straw*DSLP        1      132.7      132.7      132.7    0.35  0.552
Error           287   107558.3   107558.3      374.8
Total           299   205189.5

Term                Coef     StDev        T      P
Constant          55.974     3.856    14.52  0.000
DSLP             -0.6155    0.2261    -2.72  0.007
DSD1            -0.02851   0.02840    -1.00  0.316
Design S
1                -20.914     2.458    -8.51  0.000
Rainfall
H                  5.832     3.212     1.82  0.070
L                  1.579     4.045     0.39  0.697
Fertiliz
F                  3.066     2.171     1.41  0.159
Straw
S                 -3.026     2.166    -1.40  0.163
DSLP*Design S
     1            0.5833    0.2307     2.53  0.012
DSLP*Rainfall
     H            0.0130    0.2833     0.05  0.963
     L           -0.2839    0.3007    -0.94  0.346
DSLP*Fertiliz
     F           -0.0659    0.1820    -0.36  0.718
```

Note: `DSLP` is days since last precipitation and `DSD1` is days since December 1, 2000.

General Linear Model

```
Factor     Type Levels Values
Design S  fixed      2 1 2

Analysis of Variance for root(Tot, using Adjusted SS for Tests

Source          DF     Seq SS     Adj SS     Adj MS       F      P
DSLP             1       7092       7953       7953   20.04  0.000
Design S         1      78675      32163      32163   81.02  0.000
Design S*DSLP    1       1926       1926       1926    4.85  0.028
Error          296     117497     117497        397
Total          299     205190

Term               Coef     StDev        T      P
Constant         56.844     2.304    24.67  0.000
DSLP            -0.8945    0.1998    -4.48  0.000
Design S
1               -20.740     2.304    -9.00  0.000
DSLP*Design S
     1           0.4401    0.1998     2.20  0.028
```

Note: `DSLP` is the number of days since the previous precipitation.

11.1.6 Total Sediment

Minitab Output:

General Linear Model

```
Factor      Type Levels Values
Design S  fixed       2 1 2
Rainfall  fixed       3 H L M
Fertiliz  fixed       2 F X
Straw     fixed       2 S X

Analysis of Variance for RootSedi, using Adjusted SS for Tests

Source      DF      Seq SS      Adj SS      Adj MS        F       P
DSLP         1       0.322       0.530       0.530     0.67   0.413
DSD1         1      32.378      20.653      20.653    26.23   0.000
Design S     1      45.492      25.917      25.917    32.92   0.000
Rainfall     2      21.824      21.182      10.591    13.45   0.000
Fertiliz     1       4.552       4.395       4.395     5.58   0.019
Straw        1       5.652       5.652       5.652     7.18   0.008
Error      292     229.895     229.895       0.787
Total      299     340.116

Term           Coef      StDev         T       P
Constant     2.2497     0.1757     12.80   0.000
DSLP      -0.007617   0.009288     -0.82   0.413
DSD1      -0.006496   0.001268     -5.12   0.000
Design S
1          -0.35915    0.06260     -5.74   0.000
Rainfall
H           0.33466    0.08133      4.11   0.000
L           -0.0438     0.1043     -0.42   0.675
Fertiliz
F           0.12138    0.05137      2.36   0.019
Straw
S          -0.13737    0.05127     -2.68   0.008
```

Note: `DSLP` is days since last precipitation and `DSD1` is days since December 1, 2000.

Vegetation Cover Analysis

The vegetation cover analyses can be quickly summarized by the following two tables. The first indicates which parameters in the model are significant according to each model (Note: hypothesis tests with the logistic regression are based on the Wald test while the tests from the ANOVA methods are the F test.):

	Overstory			Understoy		
Parameter	Logistic Regressin	Weighted ANOVA	Arcsine Root	Logistic Regressin	Weighted ANOVA	Arcsine Root
Rainfall (α_i)	***	***	***	***	***	***
Fertilizer (β_j)					**	**
Treatment (γ_k)						
Box-division (δ_l)					*	
Rain*Fertilizer ($\alpha\beta_{ij}$)	***			***	**	**
Rain*Treatment ($\alpha\gamma_{ik}$)	*			*		
Rain*Box-half ($\alpha\delta_{il}$)				***	**	**
Fert*Treatment ($\beta\gamma_{jk}$)				*		
Fert*Box-half ($\beta\delta_{jl}$)				***		**
Treat*Box-half ($\gamma\delta_{kl}$)				**		

*** = p-value<.001, ** = .001<p-value<.01, *= .01<p-value<.05

The second shows estimated proportion covers according to each model:

Rain	Fert	Treat	Box-Half	Overstory Logistic Reg	Overstory ANOVA	Overstory Arcsine root	Understory Logistic Reg	Understory ANOVA	Understory Arcsine root
H	F	S	L	0.9281	0.9425	0.9297	0.7066	0.7140	0.7017
H	F	S	U	0.9444	0.9634	0.9573	0.8442	0.8650	0.8513
H	F	T	L	0.9324	0.9398	0.9366	0.7178	0.7519	0.7508
H	F	T	U	0.9251	0.9235	0.9259	0.9013	0.9608	0.9402
H	X	S	L	0.7628	0.8292	0.8344	0.5651	0.6221	0.5650
H	X	S	U	0.8247	0.8228	0.8149	0.5441	0.6653	0.6606
H	X	T	L	0.8167	0.8077	0.7984	0.6605	0.7632	0.7546
H	X	T	U	0.8158	0.9060	0.8594	0.7404	0.7582	0.7626
M	F	S	L	0.8055	0.9442	0.8961	0.7694	0.9407	0.9208
M	F	S	U	0.8145	0.9481	0.9408	0.9058	0.6904	0.6801
M	F	T	L	0.9190	0.9491	0.9285	0.6711	0.9308	0.9217
M	F	T	U	0.8910	0.8730	0.8486	0.9037	0.5442	0.5504
M	X	S	L	0.8448	0.9125	0.8866	0.5475	0.6158	0.6012
M	X	S	U	0.8652	0.9334	0.9434	0.5873	0.5218	0.5112
M	X	T	L	0.9507	0.9357	0.9314	0.5120	0.6513	0.6539
M	X	T	U	0.9393	1.0015	1.0000	0.6632	0.4081	0.4092
L	F	S	L	1.0000	1.0081	0.9979	0.4125	0.4846	0.4901
L	F	S	U	0.9951	1.0050	0.9998	0.5050	0.3226	0.3130
L	F	T	L	1.0000	0.9744	0.9864	0.2974	0.4569	0.4836
L	F	T	U	0.9850	0.9858	0.9994	0.4952	0.4487	0.4740
L	X	S	L	1.0000	0.9936	0.9942	0.4846	0.4142	0.3842
L	X	S	U	0.9850	1.0077	1.0000	0.3380	0.4085	0.4268
L	X	T	L	1.0000	0.9783	0.9839	0.4455	0.4319	0.4299
L	X	T	U	0.9651	0.8991	0.8922	0.4319	0.1407	0.1402
N	F	S	L	0.9101	0.9138	0.8922	0.1404	0.0965	0.0976
N	F	S	U	0.8923	0.9358	0.9379	0.0961	0.0804	0.0988
N	F	T	L	0.9249	0.9132	0.8933	0.1148	0.0940	0.1161
N	F	T	U	0.8727	0.8071	0.7874	0.1187	0.5819	0.5554
N	X	S	L	0.8887	0.9094	0.9059	0.1640	0.1828	0.1845
N	X	S	U	0.8789	0.9253	0.9060	0.0495	0.0277	0.0418
N	X	T	L	0.9263	0.9644	0.9572	0.1809	0.1679	0.1761
N	X	T	U	0.8861	0.9432	0.9187	0.0856	0.0707	0.0811

11.1.7 Overstory

11.1.7.1 Logistic Regression

SPSS Output (partial)

Logistic Regression

---------- Hosmer and Lemeshow Goodness-of-Fit Test-----------
-

	VEG = .00		VEG = 1.00		
Group	Observed	Expected	Observed	Expected	Total
1	76.000	61.714	224.000	238.286	300.000
2	50.000	54.282	250.000	245.718	300.000
3	32.000	41.736	268.000	258.264	300.000
4	40.000	34.633	260.000	265.367	300.000
5	21.000	30.656	279.000	269.344	300.000
6	23.000	23.107	277.000	276.893	300.000
7	17.000	21.314	283.000	278.686	300.000
8	25.000	16.557	275.000	283.443	300.000
9	5.000	6.505	295.000	293.495	300.000
10	2.000	.537	498.000	499.463	500.000

	Chi-Square	df	Significance
Goodness-of-fit test	21.3831	8	.0062

------------------------ Variables in the Equation ------------------------

Variable	B	S.E.	Wald	df	Sig	R	Exp(B)
RAINFALL			17.2138	3	.0006	.0758	
RAINFALL(1)	7.9441	4.9585	2.5668	1	.1091	.0170	2818.9507
RAINFALL(2)	.2428	.3477	.4876	1	.4850	.0000	1.2748
RAINFALL(3)	-.8940	.3154	8.0348	1	.0046	-.0556	.4090
STRAW(1)	.1958	.3117	.3949	1	.5298	.0000	1.2163
FERTILIZ(1)	-.2380	.3028	.6180	1	.4318	.0000	.7882
V6(1)	-.2005	.3028	.4386	1	.5078	.0000	.8183
RAINFALL * STRAW			11.0505	3	.0115	.0509	
INT_1	-.9321	.8838	1.1124	1	.2916	.0000	.3937
INT_2	-.1291	.3236	.1590	1	.6900	.0000	.8789
INT_3	.8112	.3331	5.9299	1	.0149	.0449	2.2505
FERTILIZ * RAINFALL			27.3341	3	.0000	.1046	
INT_4	-.9896	.8843	1.2523	1	.2631	.0000	.3717
INT_5	-1.1516	.3336	11.9190	1	.0006	-.0713	.3161
INT_6	.5113	.3260	2.4596	1	.1168	.0154	1.6675
RAINFALL * V6			3.2109	3	.3602	.0000	
INT_7	-4.7555	4.8988	.9423	1	.3317	.0000	.0086
INT_8	.4749	.3237	2.1527	1	.1423	.0088	1.6079
INT_9	.2591	.3261	.6317	1	.4267	.0000	1.2958
INT_10	.2588	.2709	.9126	1	.3394	.0000	1.2954
INT_11	-.3855	.2633	2.1441	1	.1431	-.0086	.6801
INT_12	.1058	.2679	.1560	1	.6929	.0000	1.1116
Constant	2.3150	.2707	73.1250	1	.0000		

11.1.7.2 Weighted ANOVA

Minitab Output

Analysis of Variance for Proporti, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Rainfall	3	1.27530	1.62741	0.54247	9.24	0.000
Fertiliz	1	0.08681	0.20494	0.20494	3.49	0.068
Straw	1	0.00836	0.02020	0.02020	0.34	0.561
Box-Divi	1	0.00420	0.00086	0.00086	0.01	0.904
Rainfall*Fertiliz	3	0.52207	0.44289	0.14763	2.51	0.070
Rainfall*Straw	3	0.05969	0.07347	0.02449	0.42	0.742
Rainfall*Box-Divi	3	0.03225	0.03108	0.01036	0.18	0.912
Fertiliz*Straw	1	0.02010	0.01788	0.01788	0.30	0.584
Fertiliz*Box-Divi	1	0.00014	0.00010	0.00010	0.00	0.968
Straw*Box-Divi	1	0.07669	0.07669	0.07669	1.31	0.259
Error	45	2.64332	2.64332	0.05874		
Total	63	4.72893				

11.1.7.3 Arcsine Root ANOVA

Analysis of Variance for ArcSineR, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Rainfall	3	0.92538	0.92538	0.30846	13.38	0.000
Fertiliz	1	0.03715	0.03715	0.03715	1.61	0.211
Straw	1	0.01539	0.01539	0.01539	0.67	0.418
Box-Divi	1	0.00937	0.00937	0.00937	0.41	0.527
Rainfall*Fertiliz	3	0.12977	0.12977	0.04326	1.88	0.147
Rainfall*Straw	3	0.04555	0.04555	0.01518	0.66	0.582
Rainfall*Box-Divi	3	0.03321	0.03321	0.01107	0.48	0.698
Fertiliz*Straw	1	0.00173	0.00173	0.00173	0.08	0.785
Fertiliz*Box-Divi	1	0.00000	0.00000	0.00000	0.00	0.999
Straw*Box-Divi	1	0.02626	0.02626	0.02626	1.14	0.292
Error	45	1.03760	1.03760	0.02306		
Total	63	2.26141				

11.1.7.4 Multiple Comparisons

For the 24 comparisons of interest in each ANOVA (comparing each FertxStraw level within a rainfall regime) we conclude a significant difference if the difference is larger than 0.351.

Variable	MCTTT	N	Mean	Median	TrMean	StDev
ArcSineR	HFS	4	1.3843	1.3694	1.3843	0.0297
	HFX	4	1.2539	1.2665	1.2539	0.0700
	HXS	4	1.0699	1.0357	1.0699	0.1003
	HXX	4	1.1674	1.1600	1.1674	0.0419
	LFS	4	1.4998	1.4998	1.4998	0.0819
	LFX	4	1.5708	1.5708	1.5708	0.0000
	LXS	4	1.5708	1.5708	1.5708	0.0000
	LXX	4	1.4586	1.4701	1.4586	0.1309
	MFS	4	1.137	1.127	1.137	0.369
	MFX	4	1.3897	1.3694	1.3897	0.1334
	MXS	4	1.2764	1.3267	1.2764	0.1353
	MXX	4	1.2410	1.2490	1.2410	0.0160
	NFS	4	1.3126	1.2862	1.3126	0.0851
	NFX	4	1.2022	1.2022	1.2022	0.0172
	NXS	4	1.1827	1.1873	1.1827	0.0582
	NXX	4	1.398	1.470	1.398	0.231

There are no significant differences with experiment-wide error rate 5%. There are not even any with a 10% experiment-wide error rate.

11.1.8 Understory

11.1.8.1 Logistic Regression

```
                            Parameter
              Value   Freq  Coding
                              (1)    (2)    (3)
RAINFALL
                  L    800  1.000   .000   .000
                  H    800   .000  1.000   .000
                  M    800   .000   .000  1.000
                  N    800   .000   .000   .000
V6
                  U   1600  1.000
                  L   1600   .000
FERTILIZ
                  X   1600  1.000
                  F   1600   .000
STRAW
                  X   1600  1.000
                  S   1600   .000


      Interactions:

INT_1    RAINFALL(1) by STRAW(1)
INT_2    RAINFALL(2) by STRAW(1)
INT_3    RAINFALL(3) by STRAW(1)
INT_4    FERTILIZ(1) by RAINFALL(1)
INT_5    FERTILIZ(1) by RAINFALL(2)
INT_6    FERTILIZ(1) by RAINFALL(3)
INT_7    RAINFALL(1) by V6(1)
INT_8    RAINFALL(2) by V6(1)
INT_9    RAINFALL(3) by V6(1)
INT_10   FERTILIZ(1) by STRAW(1)
INT_11   STRAW(1) by V6(1)
INT_12   FERTILIZ(1) by V6(1)
_


Estimation terminated at iteration number 4 because
Log Likelihood decreased by less than .01 percent.

 -2 Log Likelihood     3456.524
 Goodness of Fit       3229.165
 Cox & Snell - R^2         .263
 Nagelkerke - R^2          .351
```

---------- Hosmer and Lemeshow Goodness-of-Fit Test-----------

	VEG = .00		VEG = 1.00		
Group	Observed	Expected	Observed	Expected	Total
1	274.000	276.871	26.000	23.129	300.000
2	262.000	262.611	38.000	37.389	300.000
3	249.000	235.780	51.000	64.220	300.000
4	182.000	179.763	118.000	120.237	300.000
5	155.000	157.468	145.000	142.532	300.000
6	128.000	143.897	172.000	156.103	300.000
7	130.000	130.014	170.000	169.986	300.000
8	106.000	100.518	194.000	199.482	300.000
9	82.000	83.520	218.000	216.480	300.000
10	70.000	67.556	430.000	432.444	500.000

	Chi-Square	df	Significance
Goodness-of-fit test	7.9766	8	.4358

----------------------- Variables in the Equation -----------------------

Variable	B	S.E.	Wald	df	Sig	R	Exp(B)
RAINFALL			156.8482	3	.0000	.1844	
RAINFALL(1)	1.4585	.2580	31.9641	1	.0000	.0822	4.2995
RAINFALL(2)	2.6912	.2663	102.1387	1	.0000	.1503	14.7490
RAINFALL(3)	3.0171	.2717	123.3499	1	.0000	.1654	20.4316
STRAW(1)	-.2306	.2444	.8904	1	.3454	.0000	.7940
FERTILIZ(1)	.1831	.2494	.5393	1	.4627	.0000	1.2010
V6(1)	-.4290	.2600	2.7229	1	.0989	-.0128	.6512
RAINFALL * STRAW			8.2802	3	.0406	.0227	
INT_1	-.2756	.2655	1.0774	1	.2993	.0000	.7591
INT_2	.2853	.2752	1.0746	1	.2999	.0000	1.3301
INT_3	-.2611	.2755	.8978	1	.3434	.0000	.7702
FERTILIZ * RAINFALL			42.4139	3	.0000	.0906	
INT_4	.1088	.2673	.1659	1	.6838	.0000	1.1150
INT_5	-.8005	.2784	8.2640	1	.0040	-.0376	.4491
INT_6	-1.1976	.2809	18.1706	1	.0000	-.0604	.3019
RAINFALL * V6			30.6530	3	.0000	.0746	
INT_7	.8024	.2722	8.6902	1	.0032	.0388	2.2309
INT_8	1.2401	.2849	18.9440	1	.0000	.0618	3.4558
INT_9	1.4874	.2867	26.9140	1	.0000	.0750	4.4254
INT_10	.3492	.1685	4.2959	1	.0382	.0228	1.4179
INT_11	.4672	.1682	7.7132	1	.0055	.0359	1.5955
INT_12	-.8960	.1727	26.9031	1	.0000	-.0749	.4082
Constant	-1.8121	.2226	66.2901	1	.0000		

11.1.8.2 Weighted ANOVA

Minitab Output

```
Analysis of Variance for Proporti, using Adjusted SS for Tests

Source              DF     Seq SS     Adj SS     Adj MS       F      P
Rainfall             3    40.9795    29.5132     9.8377  132.77  0.000
Fertiliz             1     1.3798     0.8822     0.8822   11.91  0.001
Straw                1     0.0373     0.0055     0.0055    0.07  0.787
Box-Divi             1     0.5307     0.3858     0.3858    5.21  0.027
Rainfall*Fertiliz    3     1.5004     1.1923     0.3974    5.36  0.003
Rainfall*Straw       3     0.3196     0.2141     0.0714    0.96  0.418
Rainfall*Box-Divi    3     0.9987     0.8757     0.2919    3.94  0.014
Fertiliz*Straw       1     0.0351     0.0508     0.0508    0.69  0.412
Fertiliz*Box-Divi    1     0.2946     0.2949     0.2949    3.98  0.052
Straw*Box-Divi       1     0.0821     0.0821     0.0821    1.11  0.298
Error               45     3.3343     3.3343     0.0741
Total               63    49.4921
```

11.1.8.3 Arcsine Root ANOVA

```
Analysis of Variance for ArcSineR, using Adjusted SS for Tests

Source              DF     Seq SS     Adj SS     Adj MS       F      P
Rainfall             3    4.96068    4.96068    1.65356   86.22  0.000
Fertiliz             1    0.24114    0.24114    0.24114   12.57  0.001
Straw                1    0.00851    0.00851    0.00851    0.44  0.509
Box-Divi             1    0.06981    0.06981    0.06981    3.64  0.063
Rainfall*Fertiliz    3    0.26465    0.26465    0.08822    4.60  0.007
Rainfall*Straw       3    0.06221    0.06221    0.02074    1.08  0.367
Rainfall*Box-Divi    3    0.19902    0.19902    0.06634    3.46  0.024
Fertiliz*Straw       1    0.01120    0.01120    0.01120    0.58  0.449
Fertiliz*Box-Divi    1    0.11860    0.11860    0.11860    6.18  0.017
Straw*Box-Divi       1    0.03525    0.03525    0.03525    1.84  0.182
Error               45    0.86301    0.86301    0.01918
Total               63    6.83408
```

11.1.8.4 Multiple Comparisons

For the 24 comparisons we conclude a significant difference if the difference is larger than 0.320.

Variable	MCTTT	N	Mean	Median	TrMean	StDev
ArcSineR	HFS	4	1.0228	1.0433	1.0228	0.1610
	HFX	4	1.247	1.191	1.247	0.233
	HXS	4	0.907	0.867	0.907	0.219
	HXX	4	0.9396	0.8969	0.9396	0.1583

So, here we conclude that for High rainfall FX is better than XS. (And with a 10% family error rate, FX beats XX as well.)

	LFS	4	0.8117	0.7854	0.8117	0.1287
	LFX	4	0.6045	0.6045	0.6045	0.1626
	LXS	4	0.6370	0.6116	0.6370	0.0782
	LXX	4	0.7904	0.7954	0.7904	0.1021
	MFS	4	1.1894	1.1349	1.1894	0.1691
	MFX	4	1.113	1.138	1.113	0.241
	MXS	4	0.8459	0.8457	0.8459	0.0594
	MXX	4	0.8850	0.8965	0.8850	0.1732

Here we conclude that for Medium Rainfall FS is better than XS. (And with a 10% family error rate, FS beats XX as well.)

	NFS	4	0.3192	0.3377	0.3192	0.0501
	NFX	4	0.3653	0.4108	0.3653	0.1123
	NXS	4	0.3565	0.3377	0.3565	0.0765
	NXX	4	0.3293	0.3686	0.3293	0.1297

There are no other significant differences at experiment-wide error rate 5%.

12. PHOTOGRAPHS